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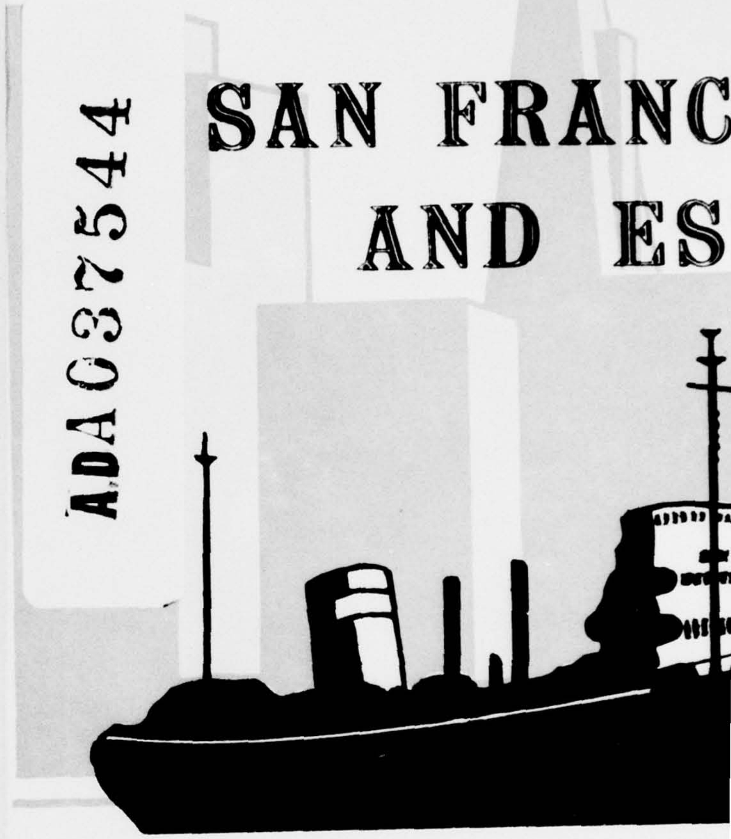

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DREDGE DISPOSAL STUDY SAN FRANCISCO BAY AND ESTUARY

APPENDIX K

MARSHLAND DEVELOPMENT

11

APRIL 1976

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U.S. Army Engineer District, San Francisco
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100 McAllister Street
San Francisco, California 94102

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DREDGE DISPOSAL STUDY SAN FRANCISCO BAY AND ESTUARY
APPENDIX K
MARSHLAND DEVELOPMENT

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Foreword

In April 1972, the San Francisco District of the United States Army Corps of Engineers initiated a three and one-half year $3 million study to quantify the impact of dredging and dredged material disposal operations on the San Francisco Bay and Estuarine environment. The study is generating factual data, based on field and laboratory studies needed for the Federal, State and local regulatory agencies to evaluate present dredging policies and alternative disposal methods.

The study is set up to isolate the questions regarding the environmental impact of dredging operations and to provide answers at the earliest date. The study is organized to investigate (a) the factors associated with dredging and the present system of aquatic disposal in the Bay, (b) the condition of the pollutants (biogeochemical), (c) alternative disposal methods, and (d) dredging technology. The study elements are intended first, to identify the problems associated with dredging and disposal operations and, second, to address the identified problems in terms of mitigation and/or enhancement.

This report presents the findings of Marshland Development Study, Appendix K. The Marsh Development Study is one of three studies which addresses specific alternatives to the present system of aquatic disposal in San Francisco Bay. The other two "alternative" studies are concerned with land and ocean disposal of dredged materials (Land Disposal, Appendix J; Ocean Disposal, Appendix L). Data from the overall study was used as the basis for preparation of the Composite Environmental Impact Statement for Maintenance Dredging in the San Francisco Bay System, which was completed in December 1975.

The entire research program was developed and administered by the San Francisco District, U.S. Army Corps of Engineers. All major work items were performed by the San Francisco Bay Marine Research Center, Inc. (MRC) under contract with the District. Dr. Curtis L. Newcombe is the Director and Chief Scientist of the Marine Research Center.

The following is an index of appendices to be published in the Dredge Disposal Study:

APPENDIX	REPORT	DATE PUBLISHED
	FINAL REPORT	
A	Main Ship Channel (San Francisco Bar)	June 1974
B	Pollutant Distribution	
C	Water Column (Water Column-Oxygen Sag)	April 1976
D	Biological Community	August 1975
E	Material Release	
F	Crystalline Matrix	July 1975
G	Physical Impact	July 1975
H	Pollutant Uptake	September 1975
I	Pollutant Availability	October 1975
J	Land Disposal	October 1974
K	Marsh Development	April 1976
L	Ocean Disposal	September 1975
M	Dredging Technology	September 1975

Conversion Factors

If conversion from the Metric to the English system is necessary, the following factors apply:

LENGTH

1 kilometer (km)=10^3 meters=0.621 statute miles=0.540 nautical miles
1 meter (m)=10^2 centimeters=39.4 inches=3.28 feet=1.09 yards=0.547 fathoms
1 centimeter (cm)=10 millimeters (mm)=0.394 inches=10^4 microns (μ)
1 micron (μ)=10^{-3} millimeters=0.000394 inches

AREA

1 square centimeter (cm^2)=0.155 square inches
1 square meter (m^2)=10.7 square feet
1 square kilometer (km^2)=0.386 square statute miles=0.292 square nautical miles
1 hectare = 10,000 square meters = 2.471 acres

VOLUME

1 cubic kilometer (km^3)=10^9 cubic meters=10^{15} cubic centimeters=0.24 cubic statute miles
1 cubic meter (m^3)=10^6 cubic centimeters=10^3 liters=35.3 cubic feet=264 U.S. gallons=1.308 cubic yards
1 liter=10^3 cubic centimeters=1.06 quarts=0.264 U.S. gallons
1 cubic centimeter (cm^3)=0.061 cubic inches

MASS

1 metric ton=10^6 grams=2,205 pounds
1 kilogram (kg)=10^3 grams=2.205 pounds
1 gr (g)=0.035 ounce

SPEED

1 knot (nautical mile per hour)=1.15 statute miles per hour=0.51 meter per second
1 meter per second (m/sec)=2.24 statute miles per hour=1.94 knots
1 centimeter per second (cm/sec)=1.97 feet per second

TEMPERATURE

Conversion Formulas $\quad {}^{o}C = \dfrac{{}^{o}F-32}{1.8} \qquad {}^{o}F = 1.8({}^{o}C) + 32$

Abstract

A marsh development study program was conducted by the San Francisco District Corps of Engineers as part of the San Francisco Bay and Estuary Dredge Disposal Study. The Marsh Development Study was initiated in August 1973, to formulate workable procedures for the artificial propagation of intertidal marsh land plants upon a dredge material substrate. On the intertidal margins of San Francisco Bay are two dominant marshland plants: California cordgrass (Spartina foliosa) and, pickleweed, consisting of several representatives of the Genus Salicornia.

Forty-eight cordgrass and 18 pickleweed test plots were established in an unconfined dredged material disposal area and were monitored for two growing seasons. In the cordgrass plots, "plugs" (transplants), rooted cuttings, seedlings, and seed starter types were comparable in terms of plant material per unit area after two growing seasons. Considering the rapid reproductive rate observed during the second growing season, it is anticipated that all the above starter types would produce plant densities comparable to natural marsh areas during the third growing season. During the monitoring period, plant density remained low in the unplanted control areas. Development of plant cover in the pickleweed plots was more rapid. Even in the unplanted controls, pickleweed exceeded all cordgrass starter types in plant material production. The use of seedlings and rooted cuttings significantly accelerated the rate of revegetation. However, the differences between planted and unplanted areas after two growing seasons was not striking in the pickleweed experiments.

There are many variables which influence the actual cost of utilizing a particular planting method. The primary variables are the size of the area to be planted and the application rate of plant materials. Given standard application rates, planting cordgrass utilizing seeds is the most cost efficient method at about $3000 per hectare. The utilization of plugs nearly triples planting costs. In the pickleweed plots only the use of rooted seedlings and rooted cuttings significantly increased the rate of colonization. Both of these methods require an expenditure of more than $10,000 per hectare.

A survey was made of potential marshland development areas in San Francisco Bay in conjunction with the study. The survey indicated that there were approximately 270 km^2 of diked lands adjacent to San Francisco Bay which could be filled to provide elevations appropriate for marsh development. The depth of fill to achieve desired elevations would seldom exceed two meters and would typically be from 0.5 to 1.0 meters in these areas. Theoretically, therefore, 200 to 250 million m^3 of dredged material could be accommodated if total utilization was made of the marsh development disposal alternative.

In the fall of 1973 construction was initiated on a 45-hectare potential marsh development area at Alameda Creek in South San Francisco Bay. Several observations were made during the construction of this area which may prove beneficial to others undertaking similar projects. During disposal operations using hydraulic dredging equipment, supernate water accumulates at the surface of the disposal area making observations of the topography of the fill impossible. A "rule of thumb" for Bay projects is that the *in situ* density of dredged material would be approximately equal to final disposal densities in the marsh development area. The average slope within the Alameda Creek disposal area after filling was generally less than 1 vertical on 500 horizontal. This gradual slope is formed as a result of the fluid nature of hydraulic slurries. Therefore, the vertical range which can be created in a confined disposal area is a function of its size. Drainage may be promoted and vertical range optimized by locating discharge pipes near interior dikes.

The Alameda Creek marsh development project proved to be an economically practical method of disposal. Site acquisition and preparation was accomplished at a cost of only about $0.35/cubic meter of dredged material (contracting costs only, not including costs for engineering and design, and supervision and administration). In addition, because the disposal area was located in close proximity to the dredging area, material transport cost were only about $1.60/cubic meter. It is anticipated that the entire 45-hectare disposal area can be planted with an additional expenditure of about $0.25/cubic meter. Marsh development may be an attractive alternative for other dredging projects which are located near suitable diked low-lands.

DREDGE DISPOSAL STUDY SAN FRANCISCO BAY & ESTUARY
APPENDIX K
MARSHLAND DEVELOPMENT

INTRODUCTION

BACKGROUND

Only recently has there been widespread recognition of the critical value of wetlands as feeding and nursery areas for fish and fowl, as a source of energy (food) and oxygen for marine organisms, as sinks for nutrient and metal pollutants, and as stabilizers of eroding shorelines. Efforts are now underway by Federal and state agencies, academic institutions, and interested individuals along the coasts to preserve, protect, and even create marshlands. (Garbisch, 1973; Woodhouse et al, 1974).

Historic Reclamation of Marshlands. The restoration of marshlands is a particularly important issue in California, for the State has the dubious distinction of being the Nation's leader in the destruction of marshes and wetlands. Since California was admitted into the Union (1850) more than 1000 km^2 of wetlands have been diked and filled. The National Estuarine Study, completed by the U.S. Bureau of Sport Fisheries and Wildlife in 1967, indicated that California has lost 67 percent of its wetland habitats in existence within State boundaries at the close of World War II. The next most severe loss nationally was in New York State, which lost 15 percent. In Southern California, only Morro Bay retains a significant portion of its tidelands. At one time San Diego's Mission Bay supported nearly 4 km^2 of mudflat and marsh. Today, less than 0.2 km^2 of marsh and virtually no mudflat areas remain in Mission Bay.

When the rush for gold began in California, more than 810 km^2 of marshlands formed the shores of Suisun Bay, San Pablo Bay, and South San Francisco Bay (Figure 1). Today, fewer than 325 km^2 of marsh remain (Figure 2).

Suisun Bay. More than 85 percent of the marshlands in Suisun Bay were reclaimed during the late 1800's for use as pasturelands. Major sloughs were blocked with wooden gates connecting with an intricate system of "handmade" levees. Due to subsidence and levee failures, only 20 km^2 out of the 240 km^2 of reclaimed marshes proved to be a successful agricultural venture. With the decline of agriculture in the 30's, nearly all reclaimed marshlands were purchased by the State of California and some 200 private duck hunting clubs for management as waterfowl areas. These managed wetlands represent 10 percent of California's wetlands and support peak waterfowl populations of from one-half to three-quarters of a million birds. Only about 28 km^2 of undisturbed intertidal marshlands remain in Suisun Bay.

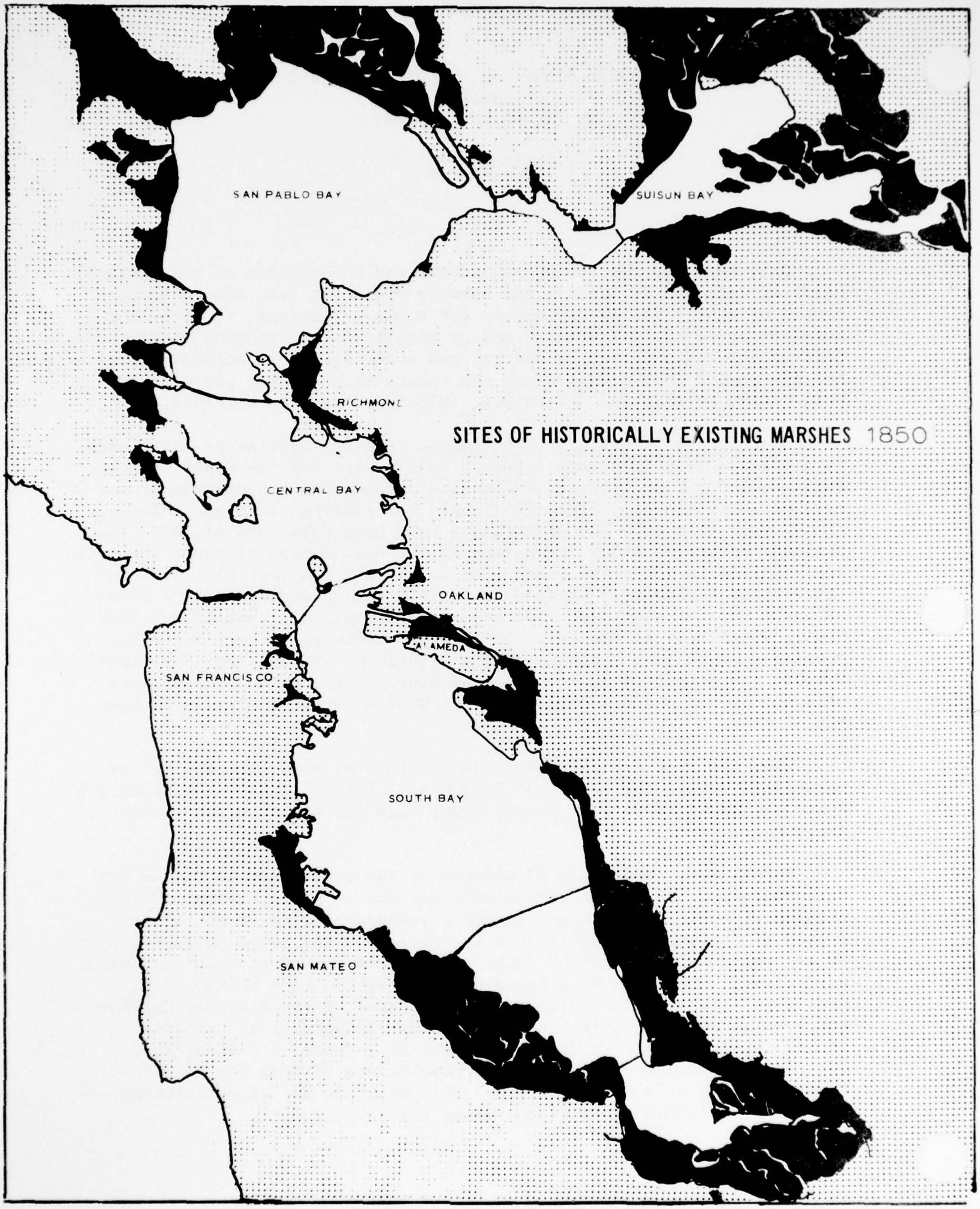

SAN PABLO BAY
SUISUN BAY
RICHMOND
SITES OF HISTORICALLY EXISTING MARSHES 1850
CENTRAL BAY
OAKLAND
ALAMEDA
SAN FRANCISCO
SOUTH BAY
SAN MATEO

FIGURE 1

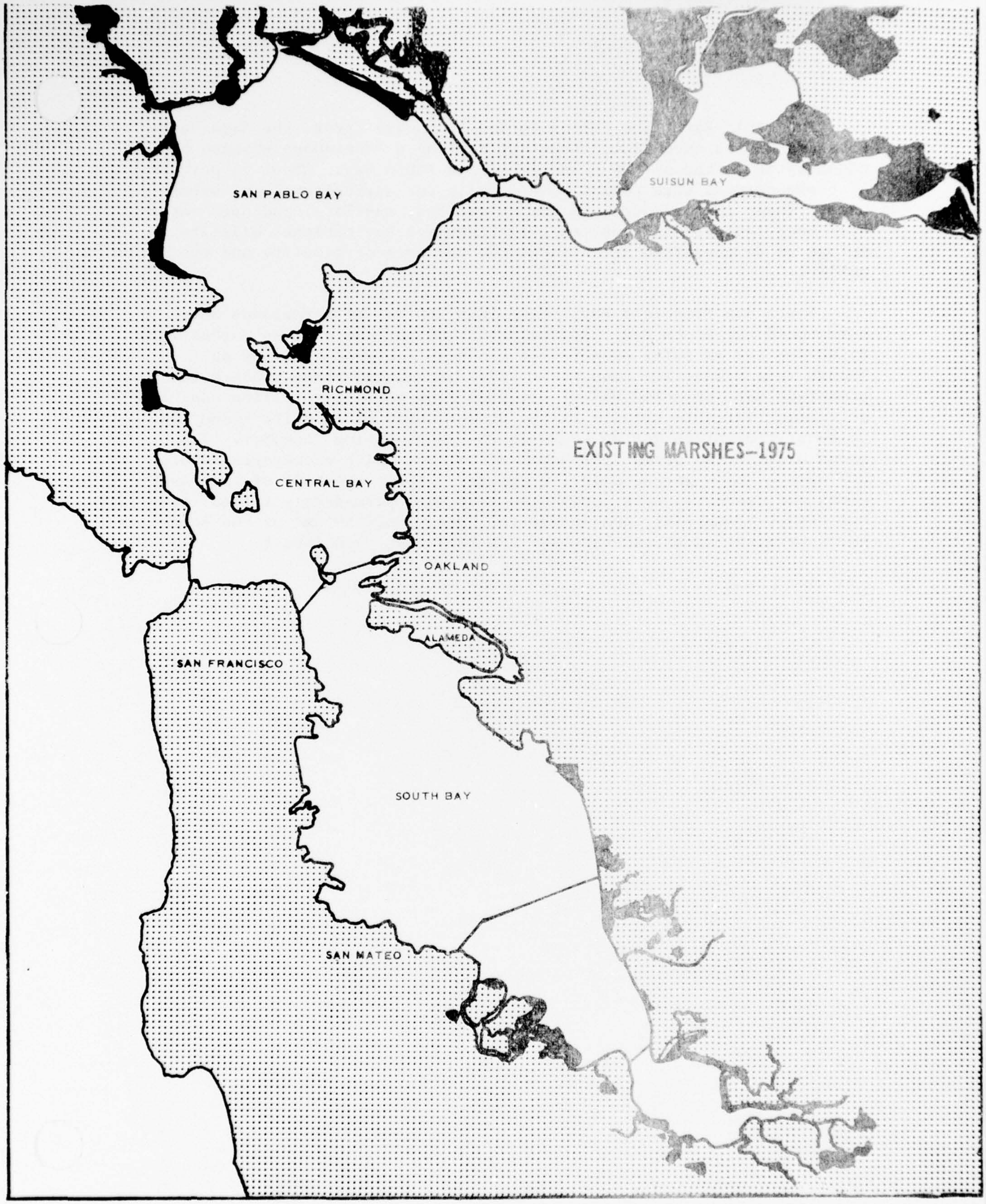

SAN PABLO BAY
SUISUN BAY
RICHMOND
EXISTING MARSHES–1975
CENTRAL BAY
OAKLAND
ALAMEDA
SAN FRANCISCO
SOUTH BAY
SAN MATEO

FIGURE 2

San Pablo Bay. The deltas formed by Sonoma Creek, the Napa, and Petaluma Rivers once flowed together forming a continuous expanse of tidal marsh on the northern shores of San Pablo Bay. About 75 percent of these marshes were reclaimed primarily for agricultural and urban uses. Today approximately 49 km^2 of marshes, mudflats, and open water have been incorporated into the San Francisco Bay National Wildlife Refuge to be preserved or enhanced for the uses of wildlife and the public.

South San Francisco Bay. More than 260 km^2 of marshlands once surrounded the South Bay. Approximately 60 percent of these areas were diked for use as solar evaporation ponds in the production of salt. Though less productive than their tidal ancestors, these ponds have preserved more than 160 km^2 of wetlands from permanent filling and have provided a valuable service in the preservation of wildlife resources. Three million birds may be found on the ponds during December. The ponds provide isolation from human activities which encourages feeding and nesting by numerous wildlife species. About one-half of the marsh areas not diked for salt production have been permanently filled, primarily for urban, commercial, and industrial uses. Only 40 km^2 of the South Bay's original marshland heritage has been preserved intact.

PREVIOUS WORK

Detailed research into the basic ecology of salt marshes began to receive emphasis nationally during the early 1950's. These early studies demonstrated the importance of marshlands to the estuarine ecosystem. Until the late 1960's, however, little information had been developed with respect to the artificial development of new marshlands. Two Federally-funded projects have greatly advanced the technology required for marsh development.

In November 1969 with the support of the US Army Corps of Engineers Coastal Engineering Research Center (CERC), marsh propagation studies were begun at North Carolina State University in Raleigh, North Carolina. The primary investigators for this work were Dr. W. W. Woodhouse, Dr. E. D. Seneca, and Dr. S. W. Broome. The results of this study were published in August 1974 as Technical Memorandum No. 46 entitled "Propagation of Spartina alterniflora for Substrate Stabilization and Salt Marsh Development". In general, the research showed that smooth cordgrass, S. alterniflora, can be successfully established on dredged material and eroding shorelines. Propagation by seeds and transplants in the spring produced stands where natural reproduction by seeds and rhizomes was occurring by fall. During the second growing season the new stands became more dense and achieved near full productivity by the start of the third growing season.

In early 1973 the Waterways Experiment Station of the Corps of Engineers began a long-range, comprehensive project known as the Dredged Material Research Program (DMRP). Fifteen research projects deal directly with artificial development of marshlands utilizing dredged material. Another seven projects cover other aspects of habitat development. These projects, in various stages of completion, are providing information on the engineering, design, construction, and planting of marsh.

STUDY OBJECTIVES

The bulk of the research conducted in conjunction with the Marsh Development Study was focused upon California cordgrass (Spartina foliosa). This species invades barren substrates in a very slow and protracted manner. Purer (1942) noted that seedlings of California cordgrass were uncommon and speculated that reproduction of the species was principally vegetative, rooting from extensive creeping rhizomes of a parent plant. Phleger (1971) questioned whether the plant actually produces viable seed as he failed to achieve germination in the laboratory utilizing several standard techniques. On the other hand, several species of the Genus Salicornia (particularly the species S. rubra) appear to be aggressive colonizers of barren areas. For this reason it was postulated at the outset of this study that little artificial encouragement would be necessary to spur colonization of dredged material by representatives of this Genus.

Until the initiation of the current marsh development studies in 1973 little was known about the artificial propagation of California cordgrass. However, the work performed by Drs. W. W. Woodhouse, E. D. Seneca, and S. W. Broome at North Carolina State University in the artificial propagation of smooth cordgrass, Spartina alterniflora - the Atlantic and Gulf coast variety, has greatly advanced the science of salt marsh development.

The current study was conducted in three phases. Phase one, entitled "Marsh Development Study, Phase I - Preliminary Investigations" was conducted between August 1973 and December 1973 to develop baseline physical and biological information on marshlands in San Francisco Bay, to formulate workable procedures for the artificial propagation of marshland plants, and to prepare plant materials for the second study phase. Specific tasks included:

1. Reviewing pertinent literature with respect to the growth, development, and propagation of salt marsh flora.

2. Conducting laboratory experiments with respect to the germination, storage, and rooting of California cordgrass and pickleweed.

3. Characterizing soils and invertebrate populations in selected intertidal areas.

4. Collecting, treating, and storing of propagules for use in field planting experiments to be conducted during phase two.

Phase two, entitled "Marsh Development Study, Phase 2 - Pilot Study" was initiated in May 1974. The primary objective of this study phase was to compare the relative success of various planting procedures upon a dredged material substrate. Specific tasks included:

1. Planting 68 test plots and 10 linear transects in an unconfined dredge material disposal area along the north bank of the Alameda Creek Flood Control Project - San Francisco Bay. (Figure 3)

2. Monitoring growth and survival of test plantings.

3. Collecting and analyzing soil samples within the test area.

4. Measuring redox potential within the test area.

5. Collecting and analyzing invertebrate populations within the test area.

6. Performing laboratory studies relating to the physiology, anatomy, and chromosomal structure of California cordgrass.

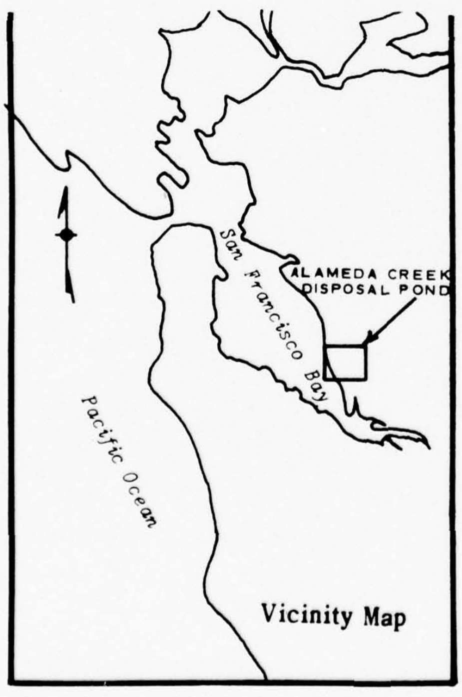
Phase three, entitled "Marsh Development Study, Phase 3 - Final Investigations" was initiated in February 1975. This final phase included.

1. Continued monitoring of the growth and survival of test plantings through the second growing season.

2. Additional collection and analysis of soils and invertebrate populations within the test area

3. Statistical analysis of the results of the two-year monitoring program.

A complete summary of the methods and procedures utilized during the first study phase, "Preliminary Investigation," and the results obtained is provided in Inclosure One. Details of the work performed during the second phase, "Pilot Study," through February 1975, may be found in Inclosure Two. Inclosure Three, "Final Investigations", provides a statistical summary of all data obtained with respect to the growth and survival of test plantings through November 1975.



Test Planting Area
Alameda Creek Flood Control Project
San Francisco Bay

FIGURE 3

SUMMARY OF FINDINGS

DESCRIPTION OF AREA

The San Francisco Bay system encompasses an area of 1190 km^2 and has a tributary area of 163,000 km^2. The system is comprised of a series of large bays interconnected by constricted straits. Seventy percent of the Bay is less than 6 m in depth. The Bay is subject to the Pacific coast semi-diurnal tidal pattern which consists of two high and two low tides per day (24.8 hours). Unlike the Atlantic coast, the two high tides differ in magnitude as do the two lows. Tidal range within the Bay generally increases in the bays inland from the Golden Gate. For instance, the mean tidal range at the Golden Gate is approximately 1.34 m, whereas, the southern tip of the South Bay (approximately 80 km from the Golden Gate) has a tidal range of 2.74 m. This broad tidal range, combined with the shallow nature of a large portion of the Bay, results in the regular exposure of expansive intertidal lands. In general, only areas above the mean tide level (MTL) are colonized by vascular plantlife. Within this area between MTL and the highest estimated high water are two dominant vegetative zones: the Spartinetium (consisting primarily of genetic variants of California cordgrass, *Spartina foliosa*) and the Salicornietium which is comprised of several representatives of the Genus Salicornia, commonly referred to as pickleweed.

MARSH FLORA IN SAN FRANCISCO BAYLANDS

California cordgrass

California cordgrass (Photo 1) occurs intermittently along the California coast and the coast of Baja California, Mexico. (Munz, 1968; Mason, 1969) It is most abundant in San Francisco Bay, San Diego County, and several estuaries in Baja California. It is sparse or absent in bays and estuaries north of San Francisco Bay. California cordgrass appears to be closely related to smooth cordgrass (*Spartina alterniflora*) which occurs along the Atlantic and Gulf coasts from Southwest Texas to Newfoundland. For the most part these two species are geographically separated by the North American continent (allopatric species). (Mobberley, 1956; Correll, 1972)

There is a controversy concerning the various height forms of the smooth cordgrass which occurs in various environments along the Atlantic and Gulf coasts. Three sympatric ecological races which differ principally in height have been described in the Southeastern United States (Adams, 1963; Cooper, 1969); a tall form (1.2-3.0 meters) which grows on creek banks, a medium form (0.6-1.2 meters) on or near levees along creeks, and a short form (0.3 meters or less) which grows away from creeks in saline soils. Mooring, *et al* (1970) concluded that on the basis of germination and seedling responses these three height forms are best described as ecophenes (phenotypes "genetically similar" responding to differences in the environments to which they were exposed. Church (1940) reported at least two levels of polyploidy[1/]; a dwarf form octoploid (2n = 56) referred to as *S. alterniflora* var. *glabra Fern* and a more robust decaploid form (2n = 70) referred to as *S. alterniflora* var. *glabra*. Marchant (1963) reported a corrected chromosome count for *S. alterniflora* var. *Glabar* of 2n = 62.

In conjunction with the field work of this study two sympatric height forms of California cordgrass in San Francisco Bay were noted, a medium, stout form (0.3-1.2 meters) which inhabits the lower marsh zone and a dwarf form (0.2-0.3 meters) with slender culms found in the high marsh in association with a depauperate, ground-hugging pickleweed. No tall form (1.2-3.0 meters) was observed.

Little literature has been published with respect to the genetic composition of California cordgrass. It was thought to be an octaploid similar to *S. alterniflora* var. *glabra* (2n = 56). (Church, 1940).

1/ "Ploidy" is the degree of repetition of the basic number of chromosomes. Most complex plants and animals have two sets of chromosomes which is a situation termed "diploidy". Organisms with more than two sets of chromosomes are polyploids (three sets-triploids, four sets-tetraploids, etc.)

CALIFORNIA CORDGRASS
(Spartina foliosa)

PHOTO 1

To further explore this question, Dr. D. R. Parnell (Inclosure 2, Appendix D) prepared microphotographs of mitotic chromosomes taken from the cells of the root primordia of robust (medium growth form) and dwarf (short growth form) of Spartina foliosa, Trin. with respect to the level of polyploidy found in each. Parnell reported a corrected diploid chromosome number of 2n=60 for both the medium and short growth forms. Therefore, no genetic differences between the medium and short forms of California cordgrass can be proven strictly upon the basis of respective levels of polyploidy.

Dr. T. H. Harvey, in his field work for this study planted parallel transects of the medium and short forms of the California cordgrass. (Inclosure 2, Appendix B and Inclosure 3, Appendix A) at various levels in the intertidal zone. Harvey observed that survival was significantly higher in the dwarf transplants, particularly at higher elevations. These results, however, do not conclusively establish that a genetic difference exists between the height forms. The observations may only reflect a difference in the respective "Physiological Adaption" of the two starter types. To date, therefore, it is not possible to state with relative surety whether or not the two height forms of California cordgrass are ecophenes (phenotypes "genetically similar" responding to differences in the environments to which they were exposed) or ecotypes (phenotypes "genetically dissimilar"). The Parnell genetic study, however, does suggest that California cordgrass is genetically different (number of chromosomes) from smooth cordgrass.

Pickleweed.

Representatives of the Genus Salicornia (pickleweeds) are ubiquitous throughout the world in alkaline soils and coastal saline environments. Local varieties include:

1. Salicornia pacifica (Photo 2) - This species is the most abundant plant in the salt marshes of San Francisco Bay. It is a bushy, woody perennial which is dormant during winter months but produces vigorous new growth each spring.

2. Salicornia rubra - This bushy, virgately erect annual inhabits high spots in salt marshes bordering San Francisco Bay. It is the first pickleweed to colonize barren and disturbed areas of the upper intertidal zone. It is the most brilliant of the pickleweeds, turning fiery red in its entirety during the fall months.

3. Salicornia depressa - This spreading or low-lying annual is not found in abundance in San Francisco Bay.

PICKLEWEED
(Salicornia sp.)

PHOTO 2

ENVIROMENTAL FACTORS AFFECTING MARSH FLORA

Tolerance to Submergence. Submergence by the tides is probably the most important environmental factor affecting the distribution of intertidal plants. Several members of the Genus Spartina are remarkably well adapted to withstand long periods of submergence. The anatomical studies conducted by Dr. Kasapligil (Inclosure 2 - Appendix C) noted several of these adaptations. Most plants exchange gases (breath) through small openings in their leaves known as stomata (from Greek meaning "mouth"). In California cordgrass the stomata are sunken and the "lip-like" guard cells which surround the stomata are accompanied by subsidiary cells equipped with branched papilla (tiny finger-like projections). Kasapligil speculates that these papilla entangle air bubbles and prevent the wetting of the stomatal apparatus during submergence. He also noted that, like many other members of the Genus Spartina, California cordgrass contains large air spaces within its roots and shoots. These air spaces (aerenchyma tissue) allow the plant to store its own supply of oxygen for respiration during submergence. (Johnson et al, 1911 - Spartina alterniflora; Purer, 1942 - Spartina foliosa). In an experiment conducted in conjunction with this study, Geoffrey Wong demonstrated oxygen transport in California cordgrass (Inclosure 2 - Appendix E). He found that this West Coast species could transport oxygen downward from and through the aerial tissues of the plant to its subsurface rhizomes and roots. This adaptation may allow the lower portions of the plant to carry on respiration and exchange of gases via the emergent stems when the plant is partially submerged. Because of these special abilities, cordgrass survives lower in the intertidal zone than any other seed-producing plant. In the upper levels of the intertidal zone where tolerance to submergence is not as critical, cordgrass is soon displaced by more aggressive weedy plant varieties, principally pickleweed.

Woodhouse, Seneca and Broome concluded from their studies in North Carolina that smooth cordgrass will usually grow in any area roughly between mean high water (MHW) and mean low water (MLW) for locations with small tidal ranges, and from MHW to mean sea level (term equivalent to 'mean tide level' on Pacific coast) for higher tidal ranges. They noted also that considerable variations may be found as a result of wave heights. Applying what we know about the ability of cordgrass to conduct air from its emergent shoots to its submerged or subsurface parts, we can clearly understand why tidal range is so important to the plant's survival at low intertidal elevations. As previously mentioned, smooth cordgrass shoots range from 0.6 to 1.2 meters in height. In an area which has only a 0.6-meter tidal range, the shoots of an average adult plant would still be exposed to the air at high tide. In an area with a 2.4-meter tidal range, an average adult plant will be totally submerged more than one-half of each day, relying entirely upon its ability to store oxygen.

Table 1 is a summary of three other observations of smooth cordgrass survival in lower intertidal areas:

TABLE 1

SMOOTH CORDGRASS
TIDAL RANGE VS. SURVIVAL

LOCATION	TIDAL RANGE Meters	LOWEST SURVIVORS Meters MLLW
Cold Springs Harbor, N.Y. (Johnson and York, 1915)	2.4	0.5
Romney Marsh, Mass. (Chapman, 1940)	2.8	0.9
Barnstable Marsh, Mass. (Redfield, 1972)	2.9	1.1

Assuming that in these studies cordgrass survived intertidal elevations equal to at least mean high water, one may estimate that smooth cordgrass populated about 80, 70, and 60 percent of the intertidal zone respectively.

Measurements of the elevational distribution of California cordgrass in San Francisco Bay (Figure 4) and at Bolinas Lagoon, eleven miles north of the Bay are shown in Table 2.

TABLE 2

CALIFORNIA CORDGRASS
TIDAL RANGE VS. SURVIVAL

LOCATION	TIDAL RANGE Meters	LOWEST SURVIVORS Meters MLLW
Bolinas Lagoon, Marin County (Rowntree, 1974)	1.4	0.6
Alameda Beach, near Bay Farm Island (Rowntree, 1974)	2.0	0.8
Palo Alto Marsh, near Palo Alto Yacht Harbor (Rowntree, 1974)	2.8	1.3

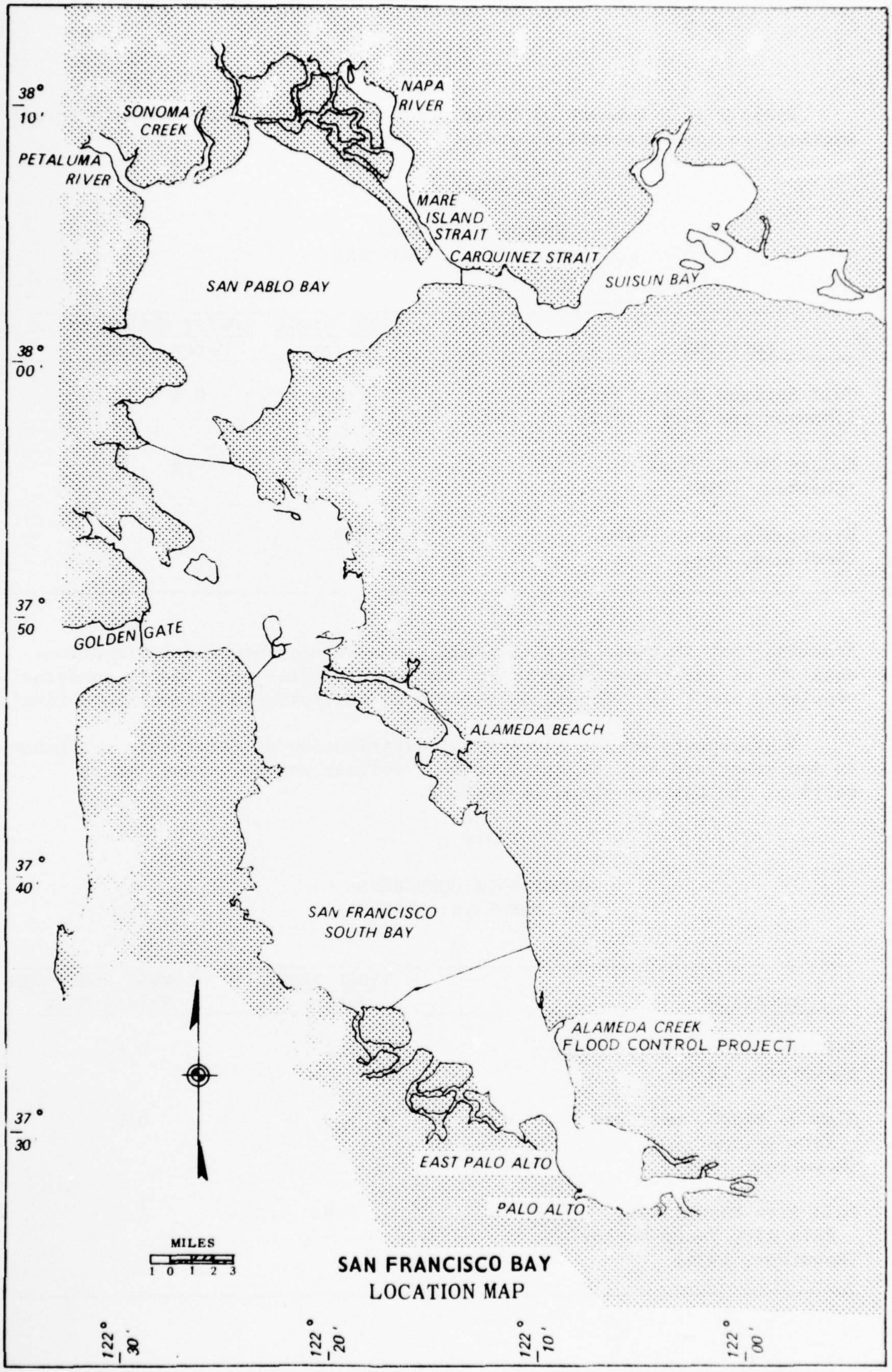

38° 10'
SONOMA CREEK
NAPA RIVER
PETALUMA RIVER
MARE ISLAND STRAIT
CARQUINEZ STRAIT
SUISUN BAY
SAN PABLO BAY
38° 00'
37° 50'
GOLDEN GATE
ALAMEDA BEACH
37° 40'
SAN FRANCISCO SOUTH BAY
ALAMEDA CREEK FLOOD CONTROL PROJECT
37° 30'
EAST PALO ALTO
PALO ALTO
MILES
1 0 1 2 3
SAN FRANCISCO BAY
LOCATION MAP
122° 30'
122° 20'
122° 10'
122° 00'

FIGURE 4

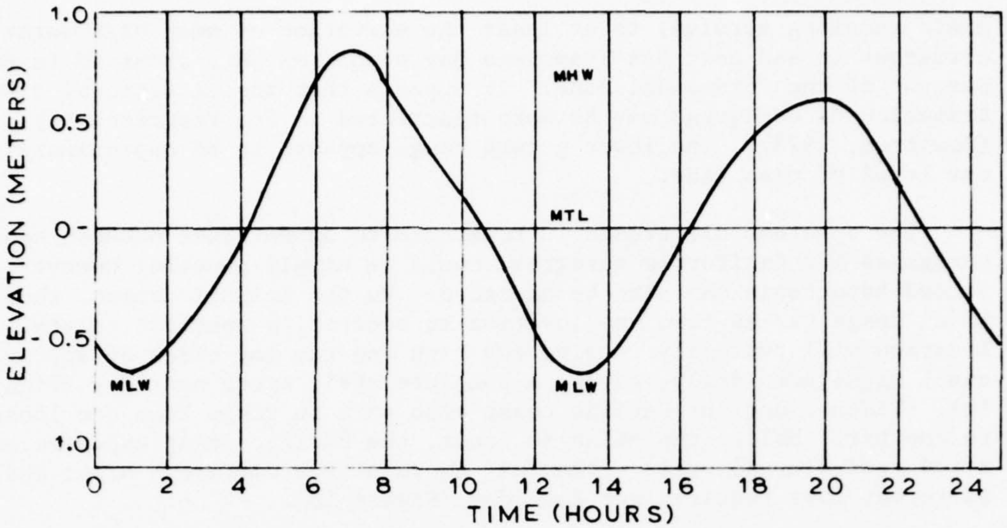
Again assuming survival to at least the elevation of mean high water, cordgrass in and near San Francisco Bay populated only about 50 to 60 percent of the intertidal zone. It appears that the elevational distribution of cordgrass may be more restricted in San Francisco Bay (Rowntree, 1973). The lower growth range appears to be approximately the level of mean tide.

The apparent difference in tolerance to submergence between smooth cordgrass and California cordgrass could be simply genetic; however, a second hypothesis can also be advanced. On the Atlantic coast, though tidal range varies from one location to another, a specific coastal location will typically receive two high and two low tides of approximately equal magnitudes daily, giving a complete cycle every half-day (Figure 5a). Tides along the Pacific coast also vary in range from one location to another. Unlike the Atlantic coast, the Pacific coast experiences a mixed semi-diurnal cycle. The full cycle of two different highs and two different lows requires one full day (Figure 5b).

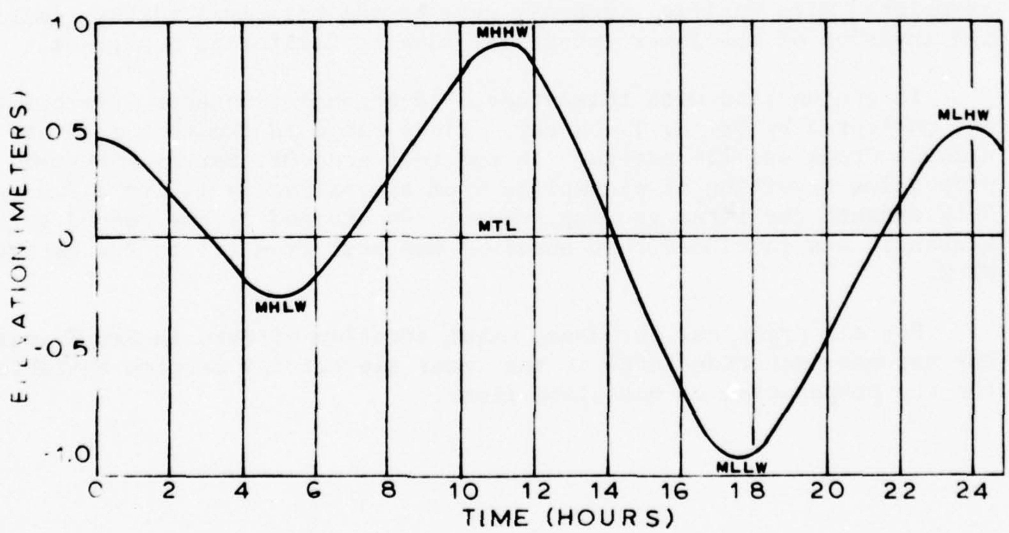
These tidal differences may affect plant survival in the lower intertidal zone. Rowntree (1973) has estimated that at Cold Springs Harbor on Long Island, New York (Johnson and York, 1915), cordgrass planted in March, the first month of the growing season, are subjected to an average period of daily submergence of about 17 hours. Rowntree also estimated that the average period of daily submergence at Alameda Beach in San Francisco Bay was slightly less (16 hours per day). However, the young plants at Cold Springs Harbor were only continuously submerged for approximately 8.5 hours in any one day. Young plants at Alameda Beach, because of the mixed semidiurnal tides, were submerged continuously up to 16.9 hours in a single day. These extended periods of submergence associated with Pacific tides may well be the principal factor limiting the invasion of the lower intertidal zone by California cordgrass.

In conjunction with this study, elevational transects were planted and monitored by Dr. H. T. Harvey. Tidal range in the test area at Alameda Creek was 2.4 meters. In the test area Dr. Harvey observed propagules surviving at elevations from approximately 1.0 to 2.7 meters, MLLW through the first growing season. By the end of the second growing season it was concluded that survival was best from 1.5 to 2.4 meters, MLLW.

For all practical purposes, marsh creation efforts in San Francisco Bay may use mean tide level as the lower elevational extreme suitable for the propagation of marshland flora.



MEAN TIDE CURVE AT ATLANTIC CITY, NEW JERSEY FIGURE 5A



MEAN TIDE CURVE AT GOLDEN GATE, SAN FRANCISCO BAY FIGURE 5B

Unlike cordgrass, pickleweed does not have the abundance of aerenchema tissue for the storage of oxygen for respiration during long periods of submergence. In general pickleweed will be found dominant only in the upper intertidal zone where submergence occurs on the average only once per day (Hinde, 1954).

Soils and Salinity (Suitability of Dredged Material). In conjunction with various elements of the Dredge Disposal Study, sediment samples were collected and analyzed in marsh areas and in dredged channels. Table 3 compares the results of sediment analysis in (1) an existing marsh in South San Francisco Bay, (2) in dredged channels throughout the Bay, (3) in a newly dredged flood control channel at Alameda Creek, (4) in a confined disposal area (Alameda Creek sediments), and (5) in an unconfined disposal area (Alameda Creek sediments).

Cordgrass has been variously reported surviving in a wide variety of substrates. Adams (1963) reported stands occurring in silt-clay substrate in Oak Island, North Carolina. Woodhouse et al (1972) reported the successful establishment of cordgrass in substrates containing from 76-97 percent sand in artificial propagation experiments also in North Carolina. In general, intertidal marshes in San Francisco Bay are predominantly clay-silt in composition. Pestrong (1969) described the sediments at the bayward edge of existing marshes in South San Francisco Bay as containing five percent sand, 15 percent coarse shell fragments and organic debris, 15 percent silt, and 65 percent clay. As shown in Table 3, sediments in dredged channels in San Francisco Bay have a similar grain size distribution.

Pestrong measured the soil moisture content of marshes at Cooley Landing in the southwestern portion of San Francisco Bay and found that pickleweed marsh sediments averaged 104 percent moisture and cordgrass marshes were about 139 percent. Moisture content in the unconfined disposal area at Alameda Creek ranged from 79-117 percent. The sediments in the confined disposal area at Alameda Creek, which had been allowed to dry and consolidate for nearly two years, ranged in moisture from 31-119 percent with the drier sediments understandably at the surface. This area was opened to tidal action in October 1975 and it is anticipated that moisture content in the confined area will be elevated to a level comparable to other intertidal areas over time.

TABLE 3 - COMPARISON OF MARSH SOILS AND DREDGED SEDIMENTS

PARAMETER	UNITS	Marsh Soils	Dredged Channels Sediments	Alameda Creek Channel Sediments	Alameda Creek Confined Dredged Material Pond 3	Alameda Creek Unconfined Dredged Material
Moisture Content	% Dry Wt.					
Mean		139.0[1]	97.5[2]	93.4[3]	53.3[4]	97.4[5]
Range		-	66-124	63-112	31-119	79-117
Grain Size	%					
Sand		15-20[1]	19.4[2]	5[3]	5[4]	-
Silt/Clay		80-85	79.6	95	95	-
Salinity	PPT Wet Wt.					
Mean		Cordgrass 22-39[6]	-	-	46.5[4]	27[5]
Range		Pickleweed 22-81[7]	-	-	30.7-88.6	18-37
Cations						
Calcium (Ca)	PPM Dry Wt.	62.0[8]	-	-	493[4]	2833.0[5]
Magnesium (Mg)	PPM Dry Wt.	14.3	-	-	1284	2370.8
Sodium (Na)	PPM Dry Wt.	-	-	-	1519	-
Potassium (K)	PPM Dry Wt.	-	-	-	-	1521.0
Anions						
Phosphate (P)	PPM Dry Wt.	35.1[8]	-	-	0.22[4]	74.5[5]
Nitrate (N)	PPM Dry Wt.	1.0	-	-	-	4.7
Chloride (Cl)	PPT Dry Wt.	-	-	-	26.8	14.6
Metals						
Iron (Fe)	PPT Dry Wt.	.1[8]			42.1[4]	.75[5]
Zinc (Zn)	PPM Dry Wt.	3.2	108.1[9]	109.7[3]	89.5	2.9
Lead (Pb)	PPM Dry Wt.	16.0	35.5	9.7	18.4	2.0
Mercury (Hg)	PPM Dry Wt.	.1	.65	.5	.5	.13
Copper (Cu)	PPM Dry Wt.	-	41.6	-	35.1	.9

1/ Pestrong, 1969 (*Spartina* zone)
2/ DDS - Appendix J
3/ Inclosure 4 - Report of Tests for Pollutants in Bottom Sediment Samples - Alameda Creek Flood Control Project, April 1972 (N = 10).
4/ Inclosure 4 - Alameda Creek Sediment Analysis November 1975, Depth 25-30 cm (N = 10).
5/ Inclosure 2 - Marsh Studies - Newcomb *et al* 1975
6/ Purer, 1942
7/ Mall, 1969
8/ Inclosure 1 - Marsh Studies - Mason 1973.
9/ DDS - Appendix B

Soil salinity is an important environmental influence upon the distribution of salt marsh plant communities. Many varieties of salt marsh plants reproduce, grow, and survive as well or better when cultivated in freshwater environments These marsh plants are refered to as "frugative halophytes," plants which tolerate but do not require saline environments. Other salt marsh plants require or prefer brackish waters. These plants are termed "true halophytes" or "salt obligates". Considerable research has been conducted with respect to smooth cordgrass concerning the question of salt requirements and/or tolerances. Studies which have subjected smooth cordgrass seeds to varying salinities indicate that freshwater is an impetus to germination. Mooring et al (1971) found that salinities above $60^{o}/oo$ (parts per thousand) virtually prohibit germination in smooth cordgrass. Additional studies of the growth of smooth cordgrass seedlings and nature plants, however, confirm that even in early developmental stages the plant is a salt obligate. Growth of smooth cordgrass seedlings is better in $5-10^{o}/oo$ salinity (interstitial water in soil) than at zero salinity. Salinities above $40^{o}/oo$, however, seem to cause substantial reduction in growth potential. Growth of adult plants was found to be optimal at salinities from 10 to $20^{o}/oo$. In field studies smooth cordgrass has been observed tolerating salinities between 2.5 and $42.5^{o}/oo$, (Harshberger, 1911).

Phleger (1971) subjected adult California cordgrass plants to nutrient solutions of from 0 to 125 percent sea water ($0.0 - 41.25^{o}/oo$ salinity). Growth and survival was best in solutions of zero salinity, indicating that California cordgrass may be a frugative halophyte. However, the Phleger experiment lasted only eight weeks and should not be considered conclusive. The transplanted adult plants certainly began the experiment with an accumulation of salt in plant tissues. In an unpublished report at San Jose State University, W. S. Chun (1973) was able to obtain 41 percent germination at zero salinity, 13 percent germination at $2.5^{o}/oo$ salinity and no germination at salinities higher than $25^{o}/oo$, using California cordgrass seeds. Purer (1942) recorded California cordgrass in southern California growing in soil salinities between $22^{o}/oo$ and $39^{o}/oo$ in the field. From this scant evidence, it is impossible to postulate with any surety whether or not California cordgrass is a true halophyte like its Atlantic coast relative.

Pickleweed can be found generally in soils with mean annual salinities greater than $18^{o}/oo$ and can survive in soils with salinities greater than $80^{o}/oo$. Competitive ability of pickleweed seems to increase rapidly where mean annual soil salinity exceeds $31^{o}/oo$. Stands of pickleweed growing in soils with salt concentrations above $70^{o}/oo$ exhibit reduced growth. Pickleweed is virtually without a floral competitor along the shores of San Francisco Bay in soils with salinities between $35.5^{o}/oo$ and $81.0^{o}/oo$ salinity (Mall, 1969).

Table 4 is a general summary of salt tolerances of pickleweed and cordgrass, utilizing available literature:

TABLE 4

MARSH PLANT SALT TOLERANCES

SALINITY (^{o}/oo)	PLANT RESPONSE
00 - 05	Germination of cordgrass seed - optimum
05 - 10	Seedling growth of cordgrass - optimum
10 - 20	Adult growth of cordgrass - optimum
20 - 30	Adult growth of pickleweed - lower limit
30 - 50	
40 - 50	Growth of cordgrass - retarded
50 - 60	Cordgrass - upper limit
60 - 70	Growth of pickleweed - retarded
70 - 80	Pickleweed - upper limit

In the unconfined disposal area at Alameda Creek, salinities ranged from 18 to 37^o/oo (well within the apparent range of salinity tolerance for either cordgrass or pickleweed). In the confined area mean soil salinities were 46.5^o/oo, which would potentially retard the growth of cordgrass in the area. However, moisture content in the confined area at the time of sampling was 53.3^o/oo (mean). As soil moisture in the confined disposal area, through tidal action, reaches parity with other intertidal areas (104 to 139.0 percent moisture), one would anticipate a depression of soil salinity to a level of less than 30^o/oo. In addition, the salt concentrations of the interstitial waters within the dredged sediments will approach an equilibrium with the tidal waters. A laboratory study of salt migration in a 1.5-meter column of saturated dredged sediments (Dredge Disposal Study - Appendix M) demonstrated that the upward migration of a detectable salt front was approximately 1 cm. per day. It is expected that in the Alameda Creek confined area (0.3-1.5 meters of fill), three to six months would be required to allow sufficient depression of salt levels.

There is no evidence of excessive or limiting elemental content in the Alameda Creek disposal areas. Nutrients (phosphates and nitrates) should not be a limiting factor in vegetative growth on dredged material for, according to Tyler (1971), most of them are probably sequestered from the tidal waters and are not likely to be washed out. Adams (1963) reported that smooth cordgrass was an iron obligate requiring substantial levels of iron. Levels of iron observed during the current studies were typically higher in the disposal areas than in existing marshes in South San Francisco Bay. During a two-year soils monitoring program in the unconfined disposal area, a significant increase in concentrations of iron, zinc, lead, and phosphate was observed (Inclosure 3).

Results of test plantings in the unconfined disposal area during 1974 and the above soil analysis support the conclusion that dredged material in San Francisco Bay is suitable for the propagation of local marsh species.

NATURAL REPRODUCTION IN MARSH FLORA

Cordgrass. The primary means of reproduction in established stands of cordgrass is asexual or vegetative. Mature plants send out subsurface runners (rhizomes) which give rise to new root systems and new culms (stems). The present studies have found that in an uncrowded condition, 75 percent of the plant biomass may lie below the soil surface. Dr. T. M. Harvey of San Jose State University initiated transplant studies in the South San Francisco Bay in 1969 using "plugs" of cordgrass approximately 10-15 cm. in diameter. He observed growth in diameter per "plug" of about three meters over an 18-month period as lateral rhizomes invaded barren substrate adjacent to his test plantings (Personal communications Dr. T. H. Harvey). As Dr. B. Kasapligil observes (Inclosure 2, Appendix C), the rhizomes of California cordgrass are firm and rigid, since they contain well-developed sclerenchymatous tissues of many layers thick." It may be noted in the field that these rigid projections are difficult to dislodge from the root mass. Rowntree (1973) speculated that vegetative invasion of California cordgrass into new substrates probably only occurs when existing marshes are disturbed mechanically by human activities such as reclamation.

When the present studies were initiated in 1973, there was no clear indication that California cordgrass stands would produce viable seed. As previously noted, earlier investigations in fact had painted a rather gloomy picture of the plant's ability to reproduce by seed within the intertidal zone.

The North Carolina studies (Woodhouse et al, 1974) have found that viable seeds are produced in smooth cordgrass stands though seed production varies greatly from year to year and from one locale to another. The number of flowering stems has been related to the degree of crowding in established stands (Taylor, 1939). Stands which are less crowded are more likely to produce a greater seed crop. In addition, studies in Maryland have indicated that seed production may be inversely related to salinity conditions (Dr. E. Garbisch, personal communication).

In conjunction with this study, several observations of seed production have been made in the San Francisco Bay area. These observations indicate that seed production along the shores of South San Francisco Bay is variable. Many of the cordgrass stands examined provided no seed and no evidence that the plants had produced seed. (Chaff was still intact in the seedless inflorescence, indicating that shattering had

not yet occurred.) The average salinity of South San Francisco Bay is $24^{o}/oo$. Seasonal variations generally range from $15^{o}/oo$ in February to $32^{o}/oo$ in September. Salinity is high in the South Bay as seasonal evaporation exceeds freshwater inflow. Locating seed-producing stands was more successful in San Pablo Bay where salinities range between 8 and $21^{o}/oo$ seasonally. Several abundant seed sources were first located in mid-October 1973 along the Petaluma River on the north side of San Pablo Bay. These crops were just maturing to ripeness and had not yet begun to shatter. Seed was found in both mature (by appearance) and seemingly young stands. However, there were nearby stands which produced very little seed.

From study observations, it appears that under natural conditions germination may begin while the seed is still in the inflorescence of the parent plant. Some of the seeds within a spike, though not in all spikes, take on a bright green color before shattering. It was later noted in laboratory experiments that this activation of chlorophyll within the embryo was generally a prelude to germination. In the laboratory, germination followed anywhere from a few days to two weeks, generally by an elongation of the radicule from which the root emerges. In other cases the shoot turns upward first, followed by the elongation of the radicule. A sample of seeds collected in the Petaluma River area were placed in fresh water in unheated rooms (approximately $10^{o}C$) immediately after threshing. Activation of chlorophyll and germination were observed in some seeds during the first week while the remaining seed displayed continuing germination with time. In nature the greening of some seeds within the inflorescence of the parent is probably the consequence of saturation of the spikes by early rains or by the condensation of fog. It was noted that these green seeds are easily removed from the inflorescence while others hang on tenaciously. It seems likely that there is a continuity of seed dispersal throughout the early part of the winter season (Dr. Herbert L. Mason, Personal Communication). Whether or not these early winter seedlings germinate, root, and survive the cold waters and winter waves after shattering has not been documented. At length the spent culms desicated, dropping the inflorescences and remaining seed into the water. In the laboratory it was observed that soaking the inflorescences in cold salt water induces the seed inclosed in the glumes to loosen and drop off. Once released from the inflorescence, the free seeds may either become trapped in irregularities on the surface of the intertidal sediments or may be carried some distances by the tides. In outside storage tanks, germinated seeds were found both rooted in the underlying substrate as well as free floating upon the water surface. Ripening in most seeds seems to continue while in the water. In the laboratory, seed stored in cold water gain in plumpness. The cold (10 to $13^{o}C$) estuarine waters of San Francisco Bay seem to inhibit germination through the winter months. Laboratory observations

indicate that storage in cold salt water (4°C and 11-12°/oo salinity) inhibited germination until the conclusion of observations in early March. Both temperature and salinity seem co-responsible for this phenomenon. Earlier germination was observed when seeds were placed in cold fresh water (4°C) or warmer salt water in unheated rooms (approximately 10°C).

It appears that most of the seed crop undergo germination in February and March. During this period salinities are still low as a result of late winter/early spring rains and snow melt. Water temperatures have begun to climb during this period to about 14°C.

Pickleweed. Pickleweed, being a weedy type of plant and like many other members of the Chenopodiaceae family, misses very few opportunities to colonize. More than 80 percent of the plant's biomass is concentrated in its aerial fleshy stems (Inclosure, 2). Vegetative reproduction is accomplished by both lateral rhizomes and rooting from prostrate (low-lying) stems. In addition, both the annual (*Salicornia rubra*) and the perennial (*S. pacifica*) produce a profusion of seeds each season. Experiments conducted as part of this study have demonstrated that pickleweed seeds germinate well even in salt water.

CULTIVATION TECHNIQUES FOR MARSH FLORA

California Cordgrass. No statistical evidence was compiled in conjunction with this study with reference to the geographical occurrence of seed producing stands of California cordgrass in San Francisco Bay. However, experience to date has suggested that seed harvesting will be more successful when conducted in the proximity of Bay tributaries. Though seed production will certainly vary from year to year, seed-producing stands were located in the following areas (Figure 4):

Petaluma River (1973 and 1974)
Napa River (1973)
Sonoma Creek (1973)
Alameda Creek (1974)
Faber Tract - East Palo Alto (1974)
(Craig Krispin, San Francisco State University, personal communication)

Cordgrass seeds mature during October. Seed collection should be timed to take place shortly before shattering. Inflorescences containing seeds will appear and feel more "plump". When the inflorescences are ready to shatter, some of the seeds will be easily dislodged by a tap of the hand. To better estimate the time of harvest, potential sites should be reconnoitered weekly beginning in late September.

Once an area producing seed is located, seed harvesting can be a relatively simple operation. Two procedures were employed to harvest seed by hand during this study.

(1) During October 1973 harvesting was performed coincident with flood tides. Harvesting was a three-man operation. One manned the boat, another bent the culms over the boat with a pole, and a third clipped the inflorescences into the boat with a hedge shears. The inflorescences were then sacked in plastic bags. This method would be preferred in areas with poor access by land.

(2) During October 1974 harvesting was performed coincident with ebb tides. Harvesting was a two-man operation. Each man wore wader boots and strapped to his back an open plastic container. The inflorescences were severed with the use of hand sickle and each man placed handfuls of the collected material into his container.

The latter method proved to be somewhat more efficient, though much more exhausting. Each worker was able to collect approximately 6 liters of seed (12 liters seed and chaff) per hour. With the use of a simple one-man mechanized harvester, Woodhouse et al (1974) found that harvest efficiency could be greatly increased. At Oregon Inlet, North Carolina one man with a harvester collected 18-20 liters of seed per hour.

After seed harvest, the threshing operation was undertaken. Fair results were obtained by placing the inflorescences in a wooden box with a #30 mesh screen bottom and spraying water from a hose on them with considerable pressure. Three such operations were required before complete shattering occurred. The last operation yielded much fewer seed than did the first two operations. Considerably better results were obtained by soaking collected material in cold salt water for two weeks before threshing. After two weeks, the inflorescences shattered easily and completely from the water pressure. The threshing reduced the volume of harvested material by approximately 45 percent.

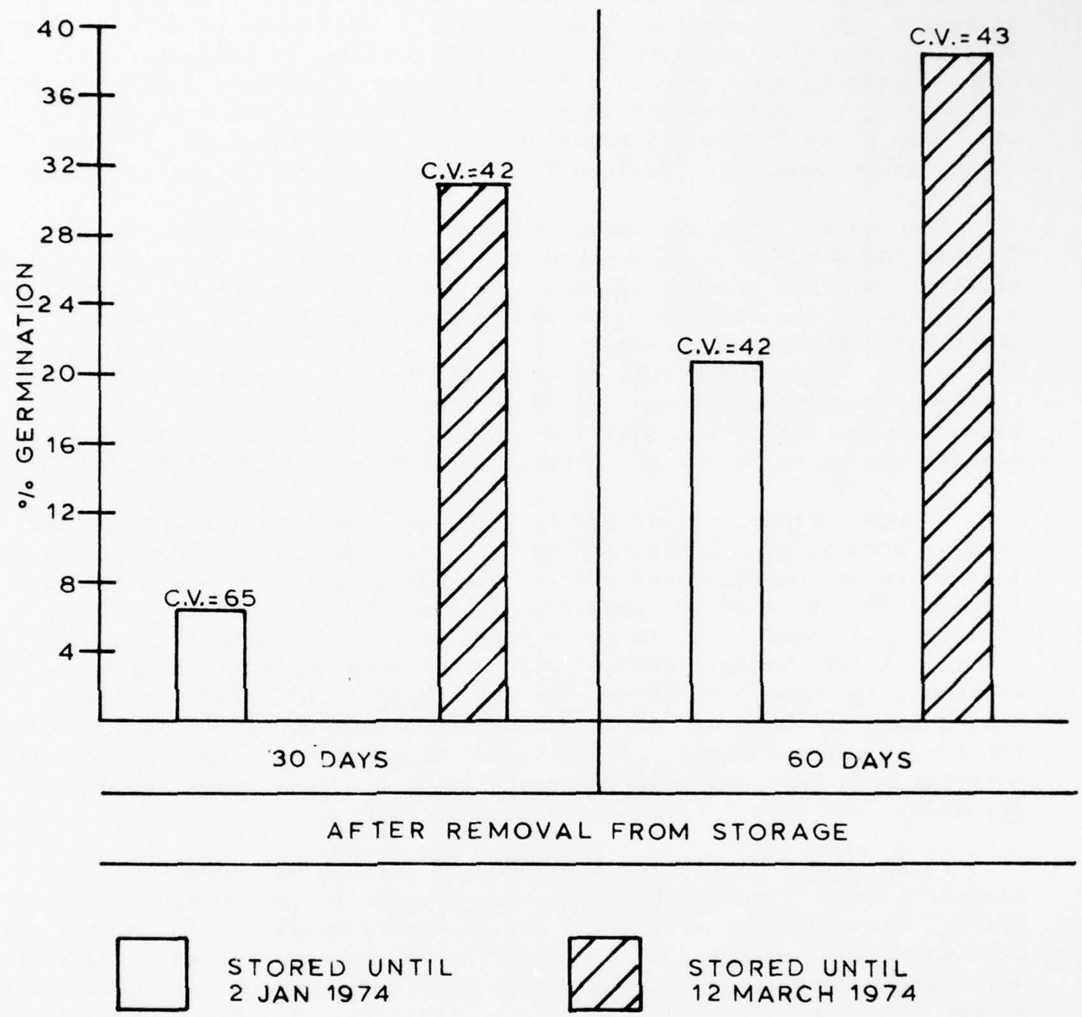
California cordgrass has a spotty and protracted sequence of seed germination. Storage of seed after threshing in either cold (6.0^{o}F) fresh or cold salt water (11-12^{o}/oo) maintains seed viability until spring planting. In fact, it appears that even in cold storage a process of after-ripening continues. In the laboratory the number of plump seeds increased rapidly in the later stages of storage. In fact, seeds stored in cold salt water until March germinated more readily when treated with fresh water than seeds taken out of storage in January (Figure 6). Storage in cold salt water proved somewhat more effective in preventing germination in storage. Seeds do not survive the conditions of either freezing or drying.

Laboratory observations also indicate that seeds stored in closed containers are subject to putrification. This problem can be eliminated during the storage period if the water medium is changed at regular periods (two weeks). Removal of the container lids also proved effective in preventing putrification.

In the nursery preparation of rooted seedlings, seeds may be germinated in petri dishes, removed after germination is observed, and implanted directly into a rooting medium. The benefit of initially germinating seeds in petri dishes is that sprouting may be observed and viable seedlings may be implanted into the medium according to a desired density. Various combinations of moist sand and vermiculity proved to be an adequate rooting medium. The addition of one-third dredged material (silty-clay) did not affect seedling survival over a two-month observation period. The overall survival of seedlings observed in the nursery from January through March ranged between 60 and 80 percent (Inclosure 1 - Appendix B).

An outdoor storage and germination procedure proved to be a practical alternative method for producing nursery seedlings. Approximately 6,000 seeds were scattered in October in an outdoor storage tank containing 4 to 5 centimeters of sand. After scattering the tank was

LENGTH OF STORAGE Vs. GERMINATION
CALIFORNIA CORDGRASS



Notes:
Storage - Refrigerated (4^oC) in Salt Water (11-18 ^{o}/oo)
Germination Treatment - Room Temperature (10-15^{o}C) in Fresh Water
Sample Size - 100
Replicates - 9
C.V. (Coefficient of Variation) = Standard Deviation/Mean x 100/1

FIGURE 6

filled with fresh water. By March approximately one-half of the seeds had germinated. Seeds began germinating in late January, reaching a peak in February.

North Carolina studies (Woodhouse et al, 1974) recommended an application rate for seeding of approximately 100 viable seeds/m^2. These investigators also suggested that this figure may be adjusted up or down, depending upon site conditions (wave exposure) and seed availability. In general, the development of cordgrass marshes in San Francisco Bay will take place in areas already protected by existing dikes. Fewer viable seeds should be required to successfully propagate these areas.

Success was obtained using cuttings collected and prepared in October and November at the onset of winter dormancy. This late collection of plant material greatly reduces the amount of time the plants must be maintained in the nursery to be used for spring planting. The most practical cutting form proved to be a crown with one or more tillars (Photo 3). After two months of observations, 75 percent of the cuttings examined showed root growth and 70 percent showed some shoot growth, either elongation or the addition of buds. A sand and vermiculite mixture proved to be the most effective rooting medium (Inclosure 1).

"Plugs", clumps of cordgrass, were dug from existing marshes and used as propagules. Collecting "plugs" was considerably more efficient in new and uncrowded stands where a very dense root mat has not been formed. "Plugs" used for purposes of this study were about 10 cm in diameter and about 15 to 20 cm in depth, containing a root mass and several aerial shoots. When planting the "plug", a hole must be excavated large enough to accept the transplant. The "plug" is then placed into the hole and native material is pushed around the base of the transplant. ("Plugs" consisting of single nodes with root and shoot material have been utilized successfully on the east coast (Woodhouse et al, 1974), but were not attempted in this study).

Pickleweed. Pickleweed sets seed in October or November. Seed-producing shoot tips may be collected, brought to the nursery, and dried. The seeds are very small and germinate readily when treated with salt water (55 percent germination after two months.) Sand or sand and vermiculite were found to be adequate rooting mediums. Germination was better in light and exposure to early morning sun greatly increased germination in outdoor plots.

Cordgrass cuttings Marine Research Center,
San Pablo Nursery PHOTO 3

Unlike cordgrass, pickleweed cuttings consist of a 10-15 cm piece of the terminal end of an upright branch system. Pickleweed goes into winter dormancy in the fall and begins its new growth in late winter. Cuttings prepared in October exhibited new growth in late December and January. Shading of cuttings aided in plant survival. Sand and vermiculite were adequate rooting mediums.

RELATIVE SUCCESS OF ALTERNATIVE CULTIVATION METHODS

Methods and Procedures. Field planting studies were initiated in May of 1974. The primary objective of this work phase was to appraise the relative success of various planting procedures in the field. In May 1974, 66 test plots (two of the original 68 plots abandoned), 5x5 meters in size, were established in the intertidal zone along the north bank of the Alameda Creek Flood Control Channel, South San Francisco Bay (Photo 4). Tidal datum estimates in this area are shown in Table 5.

TABLE 5

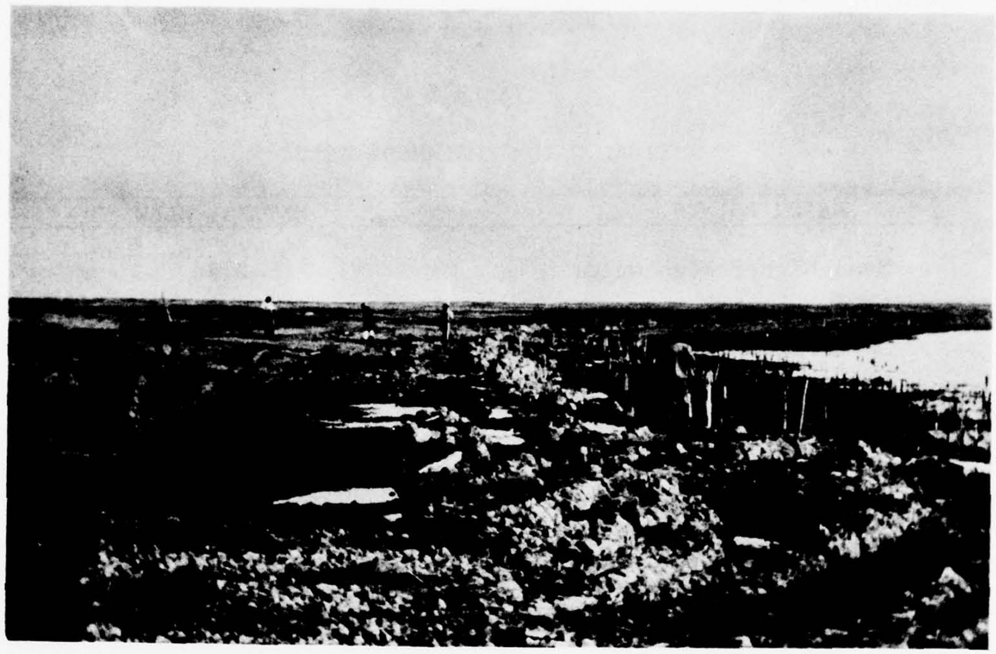
TIDAL DATUM - ALAMEDA CREEK

DATUM POINTS	METERS, MLLW
Mean higher high water	2.4
Mean high water	2.2
Mean tide level	1.3
Mean low water	0.4
Mean lower low water	0.0

Substrate within the testing area was dredged material placed by clamshell dredging operations. The material was allowed to settle approximately one year at which time (two weeks prior to the planting of the test plots) one to three feet of the surface sediments were removed exposing a new barren face (elevation from 1.8 meters to 3.3 meters, MLLW, sloping toward the channel). In the lower reaches of the test area (1.8-2.4 meters, MLLW) 48 plots were planted with cordgrass. In the upper reaches (2.7-3.3 meters, MLLW) 18 pickleweed plots were established.

Five planting methods were employed in the cordgrass field test plots:

(1) Seeding - At low tide seeds were scattered (application rate 0.6 liters per square meter or approximately 100-150 viable seeds per square meter) and raked into the substrate. Seeds were collected in October-November 1973 at the Petaluma River and stored in cold ($4^{o}C$) salt water ($20^{o}/oo$) until planting.



Test Planting Area Alameda Creek Flood Control Channel. May 1974.

Photo 4

(2) Seedlings - Seeds were germinated in the nursery in petri dishes and transfered to peat moss pots containing an equal mixture of sand and dredge material. Seedlings were approximately four months old when planted. Peat moss pots with seedlings were planted at one meter intervals in the test plots.

(3) Robust Rooted Cuttings - Robust (medium, stout from plants 0.3-1.2 meters in height) plants were collected in October-November 1973 along the shores of the Petaluma on the north shore of San Pablo Bay. Individual plants were then divided into units consisting of a crown with one or more tillars. These "cuttings" were then placed in peat moss pot containing sand and Bay sediments. Peat moss pots were planted at one meter intervals in the test area.

(4) Dwarf Rooted Cuttings - Dwarf (short, slender from plants 0.2-0.3 meters in height) plants were collected in South San Francisco Bay near Alameda Creek, prepared, and planted similar to the robust cuttings.

(5) Plugs - Plugs (10 cm in diameter, 15-20 cm in depth and containing a root mass and several aerial shoots) were excavated from existing marshes along the shores of the Petaluma River, just prior to planting. The plugs were then planted in the test area at one meter intervals (Photo 5).

Ten replicate plots of each starter type were planted. One half of the replicate plots were fertilized with a single application of commercially prepared crystalline fertilizer concomitant with planting operations. The fertilizer ("formula 48") was hand spread over the plots to be fertilized. Approximately 0.05 kilograms per square meter was used. The fertilizer contained: 8 percent nitrogen, 4 percent phosphate, 4 percent sulphur, 1 percent iron, 6 percent calcium, 0.1 percent zinc, and 0.1 percent magnesium. In addition, five fertilized and five unfertilized control plots were established.

Three types of plant materials were used in the Salicornia plots:

(1) Seedlings - Seed producing shoot tips were collected (November-December 1973), brought to the nursery, and dried. The dried seed was scattered in peat moss pots containing sand, vermiculite, and Bay sediments. Pots were planted at one meter intervals.

(2) Rooted Cuttings Unlike cordgrass, pickleweed cuttings consisted of a 10-15 cm piece of the terminal end of an upright branch system. Cuttings were rooted and planted in a manner similar to the above treatment.

"Plug" starter type. May 1974 PHOTO 5

(3) Unrooted Cuttings - Cuttings were prepared just prior to field planting, and then scattered upon designated test plots and raked into the surface with an application rate 0.6 liters per square meter.

Six replicates of each pickleweed starter type were planted with three being fertilized. Six additional control plots were established. Plantings were monitored with respect to the following parameters:

Number of plants per plot.

Height of aerial culms.

Number of stems (shoots) per plant.

Dry weight of roots and shoots.

The monitoring was conducted from the time of planting in May 1974 through November 1975.

Results. In existing marshes in San Francisco Bay cordgrass plants flower and produce seeds in the early fall, remain dormant with aerial portions of the plant dying back for a period, and initiate new vigorous shoot growth in late winter. One would expect, based upon this observation of the natural growth and reproductive cycle, that March and April would be an optimal period for seeding and planting operations.

Test plots were not planted until late May 1974 due to a delay in the excavation of the test area. This shortened the first growing season to about five months from June to October. As a result of planting shock and possibly the shortened growing season none of the propagules were sufficiently developed to produce seed the first year. By the close of the first growing season (October 1974) the seeded plots had the greatest number of plants with 1.29 plants per square meter (Figure 7). The plugs which survived the first season had grown from 15.0 grams dry weight, the approximate weight of plugs when planted, to an average of about 20.0 grams. The large unit mass of the plugs combined with their high survival rate, 80 percent, placed this starter type far ahead of all others in terms of total plant material (about 16.0 grams per square meter). The unplanted control plots remained virtually unpopulated after one season (0.02 plants per square meter).

By the end of the second growing season (October 1975) all propagules had reproduced vegetatively (Figure 8). Plant density in all planted plots increased from an average of 0.71 plants/square meter in October 1974 to 5.53 plants/square meter by October 1975. A plant was recorded as new individuals if its culms (stems) were more than 15

CORDGRASS
COMPARISON OF STARTER TYPES
AFTER ONE GROWING SEASON

STARTER TYPE	# PLANTS/ SQUARE METER	COEFFICIENT OF VARIATION	DRY WEIGHT GRAMS/PLANT	COEFFICIENT OF VARIATION
Control	0.02	254	--	--
Seeding	1.29	90	0.72	60
Seedlings	0.52	32		
Robust Rooted Cuttings	0.28	81	7.39	52
Dwarf Rooted Cuttings	0.68	23	3.23	67
Plugs	0.80	18	20.16	74

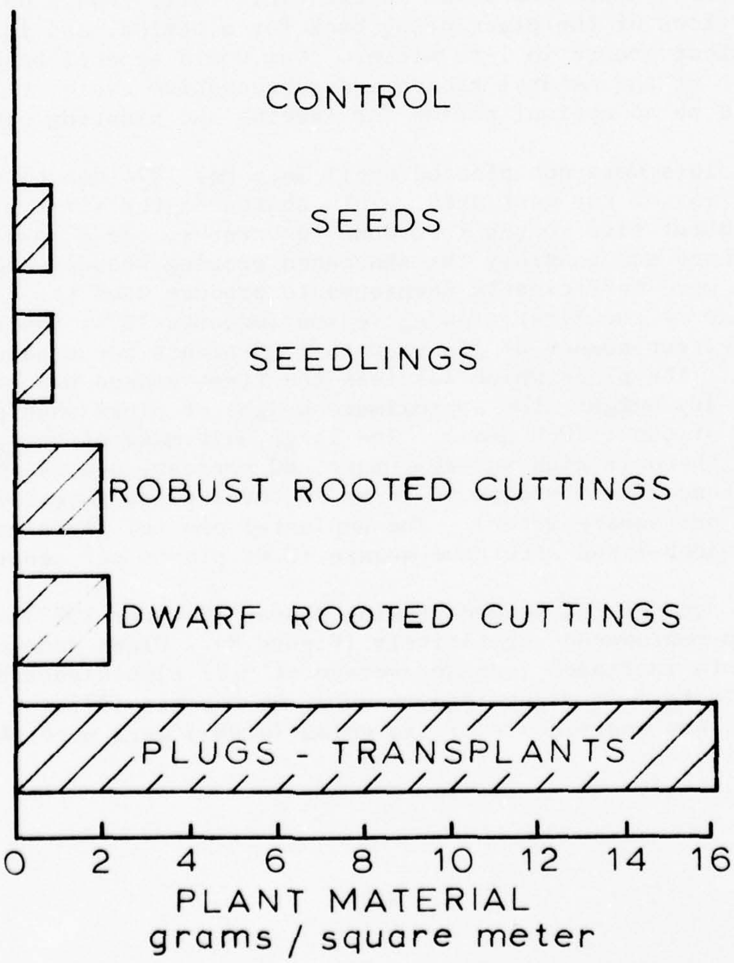


FIGURE 7.

CORDGRASS
COMPARISON OF STARTER TYPES
AFTER TWO GROWING SEASONS

STARTER TYPE	# PLANTS/ SQUARE METER	COEFFICIENT OF VARIATION	DRY WEIGHT GRAMS/PLANT	COEFFICIENT OF VARIATION
Control	0.20	165	--	--
Seeding	4.28	53	9.43	32
Seedlings	5.60	61	13.87	57
Robust Rooted Cuttings	1.04	125	12.07	70
Dwarf Rooted Cuttings	7.80	48	10.54	62
Plugs	8.92	48	14.17	46

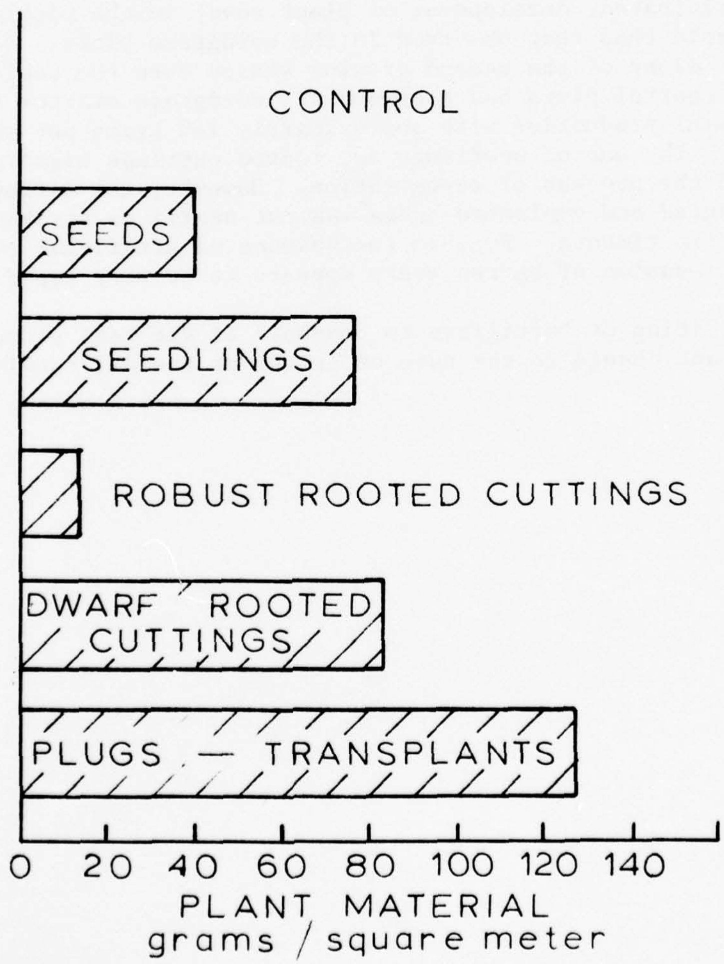


FIGURE 8

centimeters from its nearest neighbor. The seedlings, dwarf rooted cuttings, and plugs increased in number by a factor of 10 during this second growing season. Vegetative reproduction in the seeded plots and the robust rooted cutting plots was less dramatic increasing by a factor of about 3 during the second season. The slower spread within the seeded plots can probably be attributed to the shortness of the first growing season which resulted in an overall lack of seedling development (seeded plots - 0.72 grams per plant). The average weight of all starter types was comparable after two growing seasons (9.4 to 14.2 grams per plant dry weight). Photo 6 shows the planting area after the second growing season.

In the test plots the number of culms (stems) per square meter increased rapidly during the second growing season as shown in Table 6. If this rapid reproduction rate continues, one would anticipate that plant densities (culms/m^2) in the plug, dwarf rooted cutting, seedling, and seeded plots would be comparable to natural marsh areas (approximately 450 culms/m^2) mid-way through the third growing seasons (Inclosure 3). The control and robust rooted cutting plots may require two to three additional years to reach parity with existing marshes.

As anticipated, development of plant cover in the pickleweed plots was more rapid than that observed in the cordgrass plots. (Figures 9 & 10) By the close of the second growing season even the unplanted pickleweed control plots had exceeded all cordgrass starter types in plant material production with approximately 140 grams per square meter, dry weight. The use of seedlings and rooted cuttings significantly accelerated the process of revegetation. However, the differences between planted and unplanted areas was not nearly as striking in the pickleweed experiments. Even in the absence of artificial encouragement, pickleweed invasion of barren areas appears to be very rapid.

The addition of fertilizer to one-half of the test plots produced no significant change in the rate of growth or overall survival of propagules.

PICKLEWEED
COMPARISON OF STARTER TYPES
AFTER ONE GROWING SEASON

STARTER TYPE	# PLANTS/ SQUARE METER	COEFFICIENT OF VARIATION	DRY WEIGHT GRAMS/PLANT	COEFFICIENT OF VARIATION
Control	0.04	200	25.62	8
Seedling	0.69	28	23.24	64
Rooted Cuttings	0.55	69	26.25	80
Unrooted Cuttings	0.03	181	27.36	57

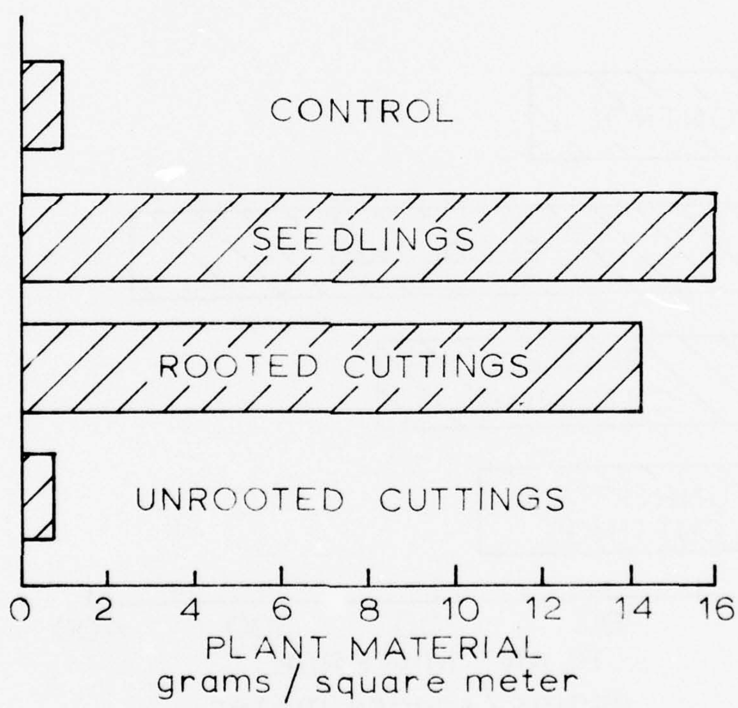


FIGURE 9

PICKLEWEED
COMPARISON OF STARTER TYPES
AFTER TWO GROWING SEASONS

STARTER TYPE	# PLANTS/ SQUARE METER	COEFFICIENT OF VARIATION	DRY WEIGHT GRAMS/PLANT	COEFFICIENT OF VARIATION
Control	2.39	52	59.05	75
Seedlings	3.35	66	111.22	49
Rooted Cuttings	1.85	79	125.12	60
Unrooted Cuttings	3.03	76	57.77	82

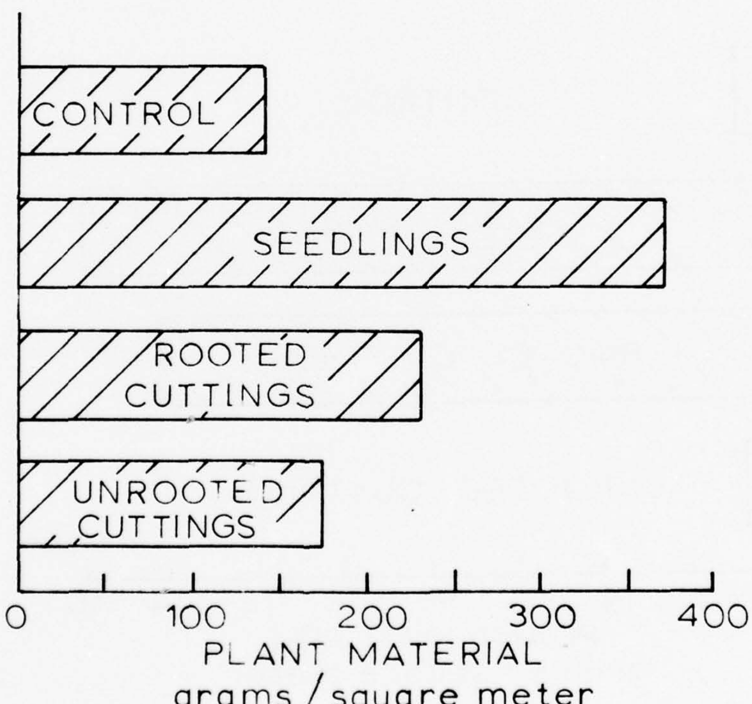


FIGURE 10

Test Planting Area Alameda Creek Flood Control Channel. August 1975.

Photo 6

TABLE 6

CORDGRASS
COMPARISON OF CULM (STEM) ABUNDANCE
OCTOBER 1974 VS. OCTOBER 1975

Planting Method	# Culms per m^2 (1974)	# Culms per m^2 (1975)	Factor of Increase
Control	0.07	2.52	36.0
Seeding	3.24	52.22	16.1
Seedlings	3.68	64.74	17.6
Robust Rooted Cuttings	0.99	6.55	6.6
Dwarf Rooted Cuttings	3.79	85.72	22.6
Plugs	5.26	88.13	16.8

RELATIVE COSTS OF ALTERNATIVE CULTIVATION METHODS

There are many variables which influence the actual cost per unit area of utilizing a particular planting method. The primary variable is the size of the area or areas to be planted. The development and utilization of cost saving equipment may be warranted if extensive planting is anticipated. The study did not address equipment development and all test plantings were made by hand.

Table 7 presents an estimated labor/cost summary for the various planting methods considered in this study. Planting by seed was the least expensive method utilized for the propagation of cordgrass. Planting "plugs" more than doubled the overall cost per unit area. It must be emphasized that these costs are based upon standard application rates. Increasing or decreasing the amount of seed used per unit area or the spacing of propagules (plugs, rooted cuttings, and rooted seedlings) would alter costs accordingly.

TABLE 7

COST/LABOR ESTIMATES FOR ALTERNATIVE PLANTING PROCEDURES*

METHOD	COST FOR PLANTING 1 HECTARE (2.5 acres)** (dollars)
CORDGRASS	
Seeds	$ 3,050
Plugs	8,600
Rooted seedlings	11,600
Rooted cuttings	12,100
PICKLEWEED	
Unrooted cuttings***	2,200
Rooted seedlings	11.300
Rooted cuttings	11,700

* Summarized from Inclosure 2.
** Costs include labor only ($10/hour); does not include nursery facilities.
*** Unsuccessful.

CONSTRUCTION OF MARSHES USING DREDGED MATERIAL

Introduction. In conjunction with this study a survey was made of potential marshland development areas in San Francisco Bay. Some 500 km^2 of historic marshlands in the Bay have been diked for salt production, agriculture, and industrial and urban development. As a result of subsidence due to extensive groundwater depletion, wind erosion and consolidation, the majority of these diked areas are now lower than when they were reclaimed 50 to 100 years ago. The survey indicated that there are approximately 270 km^2 of diked lands adjacent to San Francisco Bay which have surface elevations below mean higher high water. In Bay marsh development projects the depth of fill to achieve desired elevations will seldom exceed two meters and will typically to from 0.5 to 1.0 meters. Theoretically, therefore, 200 to 250 million m^3 could be accomodated if total utilization was made of the marsh development disposal alternative. Figure 11 delineates potential marsh reclaimation areas in the Bay.

In the fall of 1973 construction was initiated on a potential marsh development site in South San Francisco Bay. The site is a confined area used until 1965 as an evaporator pond for the production of salt. The pond was purchased by the Alameda County Flood Control District as a disposal area for the Alameda Creek Flood Control Project under construction by the U.S. Army Corps of Engineers. The area is about 0.45 km^2 (45 hectares) in size, with a length of three kilometers. The original pond bottom was at an elevation of about 1.7 meters, MLLW. Tidal range in this area of the Bay is approximately 2.5 meters though the highest estimated tide is 3.2 meters, MLLW.

Construction of Dikes. Dredging for the development of marsh substrates will generally be conducted by hydraulic dredge with pipeline to the disposal area. The broad tide flats of the Bay would require transfer facilities for use of any other type of dredging operation. Hydraulic slurries of Bay mud may contain as much as 90 percent water. To contain the slurry volume during dredging, existing dikes may have to be raised in elevation. Depending upon the dredging rate and the dimension of the disposal area, more than one meter of freeboard may be required to contain the water-sediment mixture while the material consolidates and the resulting surface water is decanted.

Dikes may also require additional height to contain the tide waters after breaching. In general, the bayward dikes in reclaimed areas are more substantial and higher than the inland dikes. The bayward dikes are responsible for protecting the inland areas from the tides and must be substantial enough to resist wave action. Once the exterior dikes are breached the interior dikes inherit the responsibility for containing

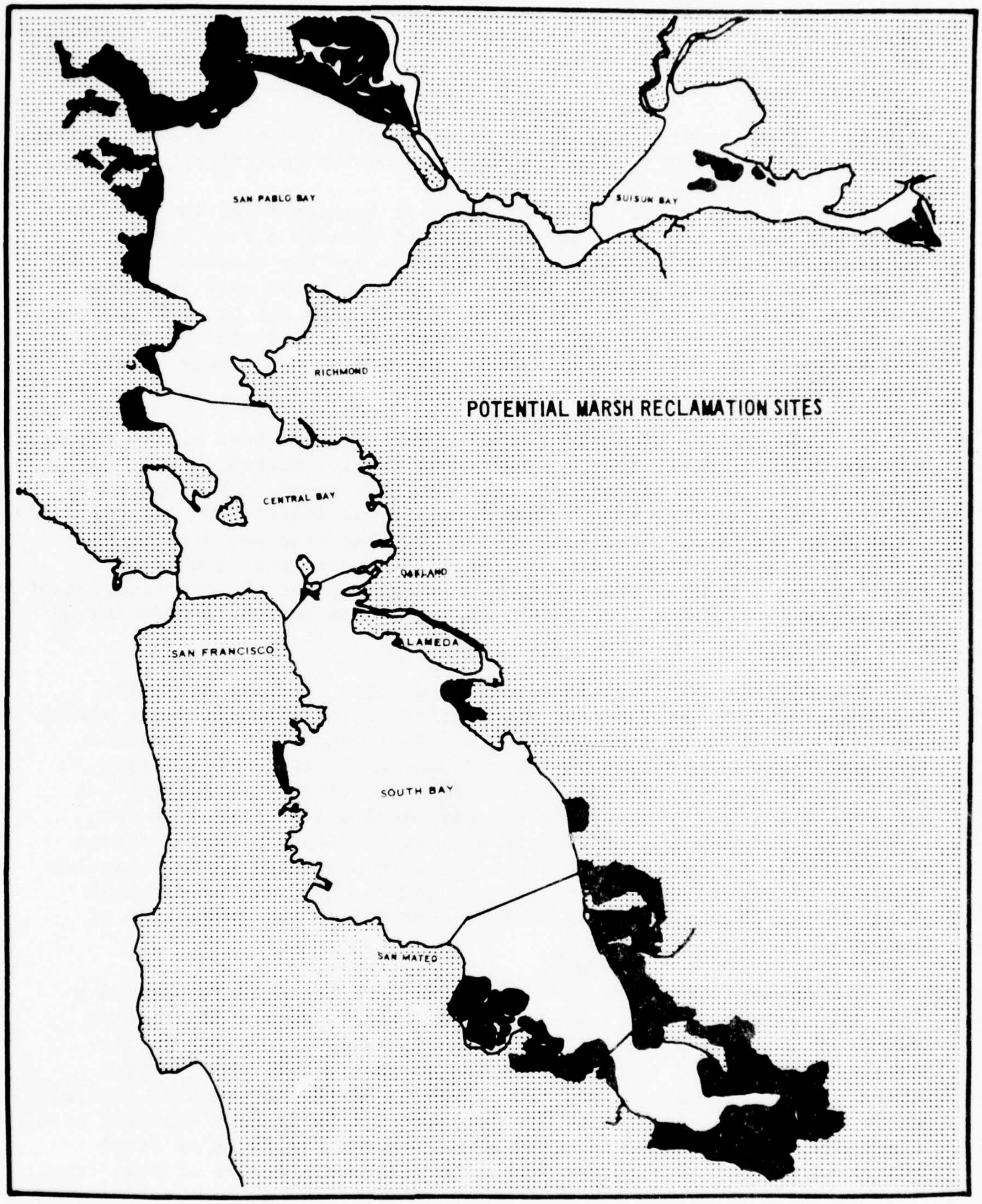

POTENTIAL MARSH RECLAMATION SITES
SAN PABLO BAY
SUISUN BAY
RICHMOND
CENTRAL BAY
OAKLAND
SAN FRANCISCO
ALAMEDA
SOUTH BAY
SAN MATEO

FIGURE 11

the tide waters. Dikes around the marsh development area must be surveyed before breaching so that low and/or weak areas can be identified and corrected. All dikes surrounding the containment area must be of an elevation higher than the estimated highest tide. One must also consider the height of waves expected in the area to allow for wave overtopping. These considerations are of particular importance when adjacent areas are being actively used for salt production or agriculture.

As previously noted the tidal range at Alameda Creek is approximately 2.5 meters and the highest estimated tide is 3.2 meters, MLLW. The design elevation of the containing dikes for the disposal pond at Alameda Creek was 3.8 meters, MLLW. It was estimated that this dike elevation would contain the estimated highest tide and protect adjacent areas from wave over-topping. In addition, this elevation allowed approximately two meters of free-board to contain the dredge material slurry during disposal.

Disposal of Dredged Material. The original pond bottom in the Alameda Creek disposal area was approximately 1.7 meters, MLLW. As previously indicated marsh areas are generally found in the upper one half of the intertidal zone. Therefore, it was intended at Alameda Creek that the final elevations of the disposal area would range from 1.7 to 3.2 meters, MLLW. Anticipated fill yardage was about 500,000 cubic meters. Several observations were made during the construction of this marsh development area which may be of help to others undertaking similar projects.

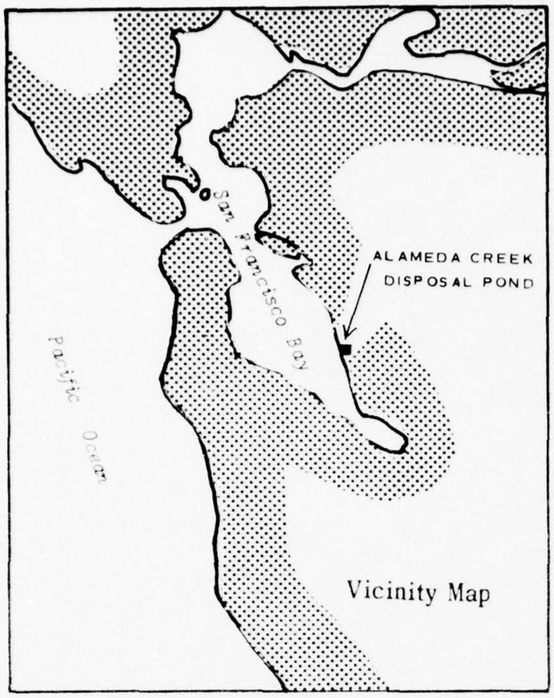
During disposal operations using hydraulic dredging equipment, supernate water accumulated at the surface of the disposal areas making observations of the topography of the fill impossible. In addition, because of the constantly varying sediment-water ratio in incoming slurries, it was not possible to accurately estimate the quantity of material which was entering the disposal area while operations were underway. This means that few, if any, corrections in the operation could be made during construction. Accurate estimates of the quantity (volume) of the material to be dredged and the quantity of material required in the disposal area must be made before the initiation of dredging.

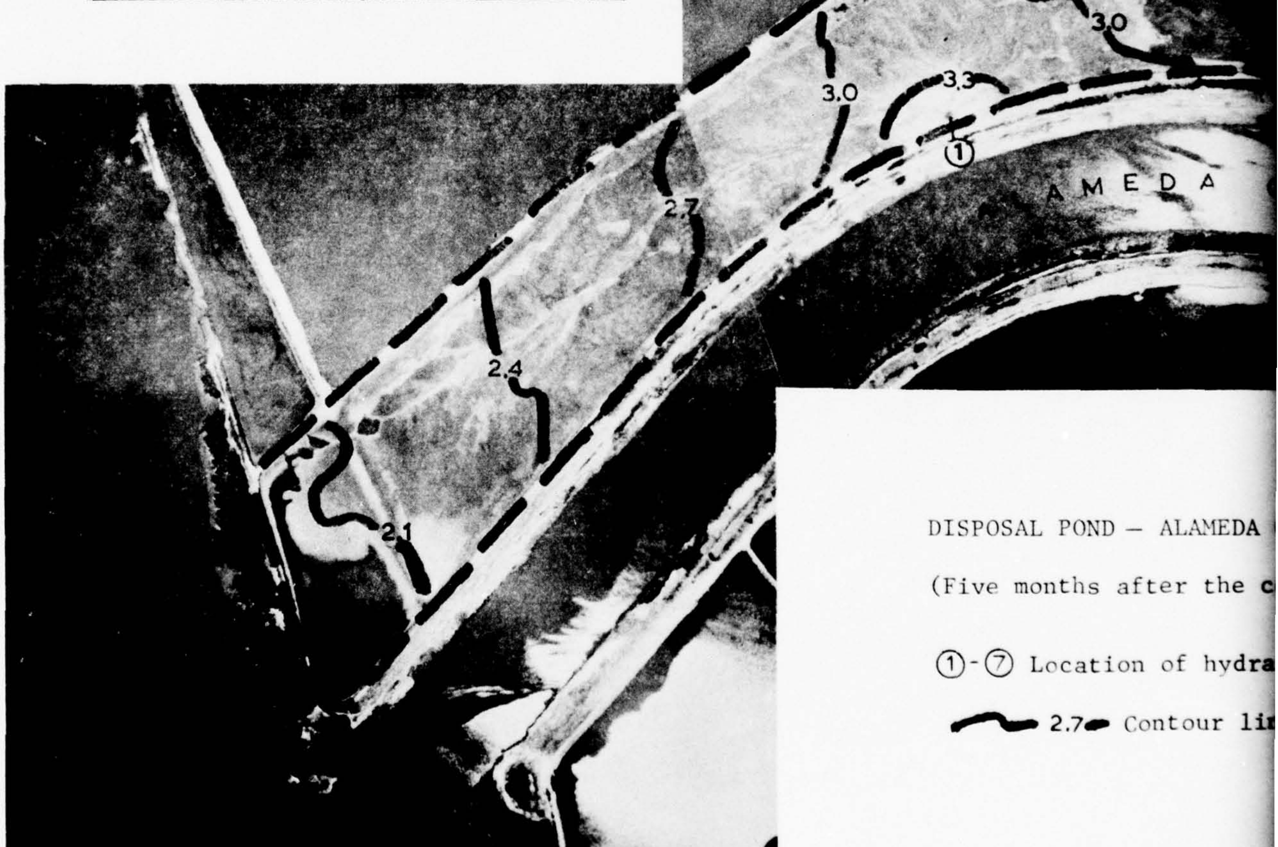
Two factors complicate the preparation of the dredging estimate: (1) Typically, commercial dredging operations excavate material in excess of that which is required by specifications to allow for irregularities created in the bottom and to assure that the required minimum depth is reached, and (2) there is little information available which compares the density of in-situ material in dredged channels with final density of dredged material after disposal in terms of final change in volume. During the hydraulic fill operation at Alameda Creek,

the amount excess of non-pay yardage was between five and ten percent of the total yardage. Though the amount of excess dredging, if any, will vary depending upon dredging conditions (depth of cut, type of equipment, and type of material), one must be cognizant of the fact that dredging in excess of specifications could occur. Sediments in dredged channels in San Francisco Bay typically contain from 85 to 95 percent silts and clays with 5 to 15 percent sand and shell fragments. Sediments in the Alameda Creek Flood Control Channel contained about 95 percent silts and clays. In-situ water content in submerged Bay sediments range between 45 and 55 percent (Dredge Disposal Study, Appendix J). Pestrong (1965) studied the substrates of existing marshes at Cooly Landing in South San Francisco Bay and found that the silt-clay fraction of marsh sediments ranged from 80 percent at the bayward edge to nearly 100 percent at the landward edge. He also noted that water content in these sediments ranged from 51 to 58 percent. Because of the similarity of dredged sediments and marsh substrates in the Bay with respect to grain size and water content, the assumption that the volume of in-place material to be dredged would be approximately equal to the final disposal volume would probably suffice for most marsh development projects in the Bay. A cursory survey of the topography of the Alameda Creek marsh development site one year after disposal indicated that the average slope within the pond was generally less than 1 vertical on 500 horizontal. This gradual slope was formed as a result of the fluid nature of the hydraulic slurries. Therefore, the vertical range which can be created in a confined disposal area is largely a function of its size. Drainage may be promoted and vertical range optimized by locating discharge pipes near interior dikes.

Photo 7 is an aerial photo of the disposal pond taken in April 1974, about six months after completion of disposal operations. Noted on the photo are approximate elevational contours at that time and location of dredged material discharge points. An excess of material was released from discharge point number one (Photo 7), creating a large mound and blocking drainage of the eastern end of the disposal area. To allow maximum tidal circulation in the pond, an artificial slough was constructed along the northern border of the disposal area during the summer of 1975. Photo 8, taken in October 1975, shows the location of the artificial slough and elevational contours after nearly two years of settling and consolidation.

<u>Opening Disposal Areas to Tidal Circulation</u>. Little information is available with respect to the dimension of a dike opening necessary to provide adequate tidal circulation within marsh development areas. Some information with respect to tidal inlet design was compiled in Dredge Disposal Study, Appendix M. The following is an excerp from Appendix M (Pages 4-16 to 4-18) concerning inlet design.





DISPOSAL POND — ALAMEDA

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2.7 Contour li

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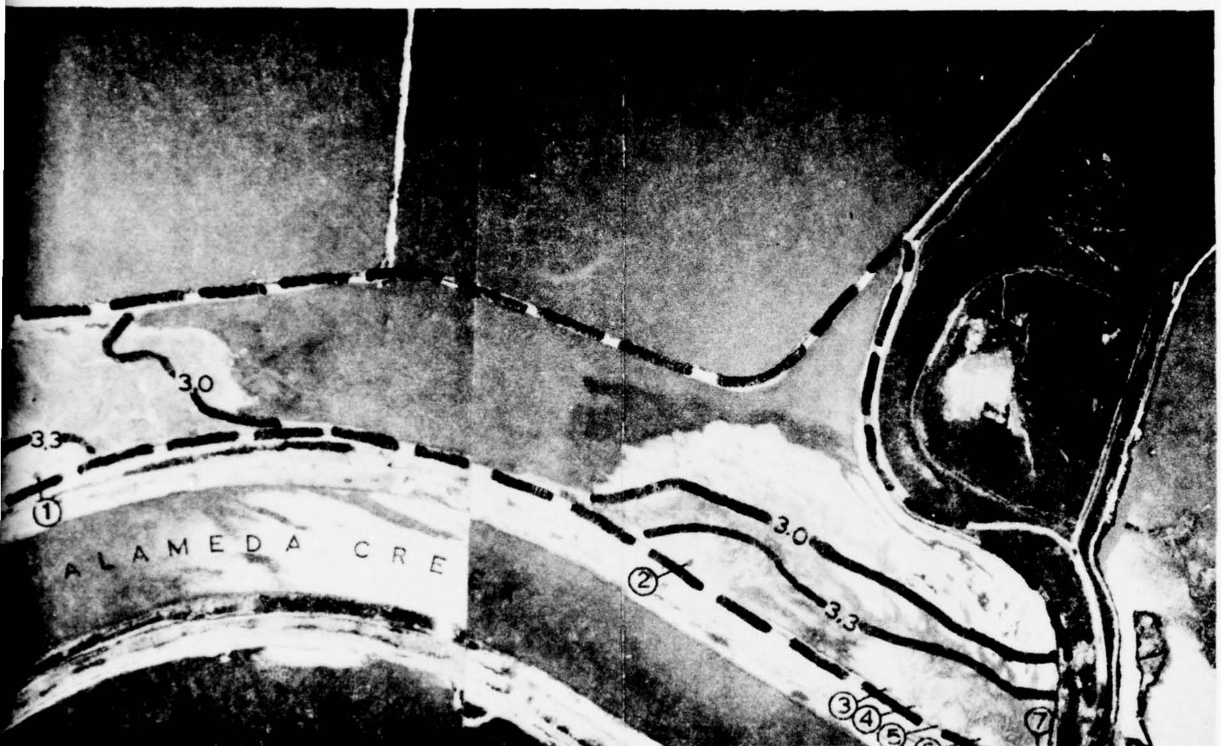
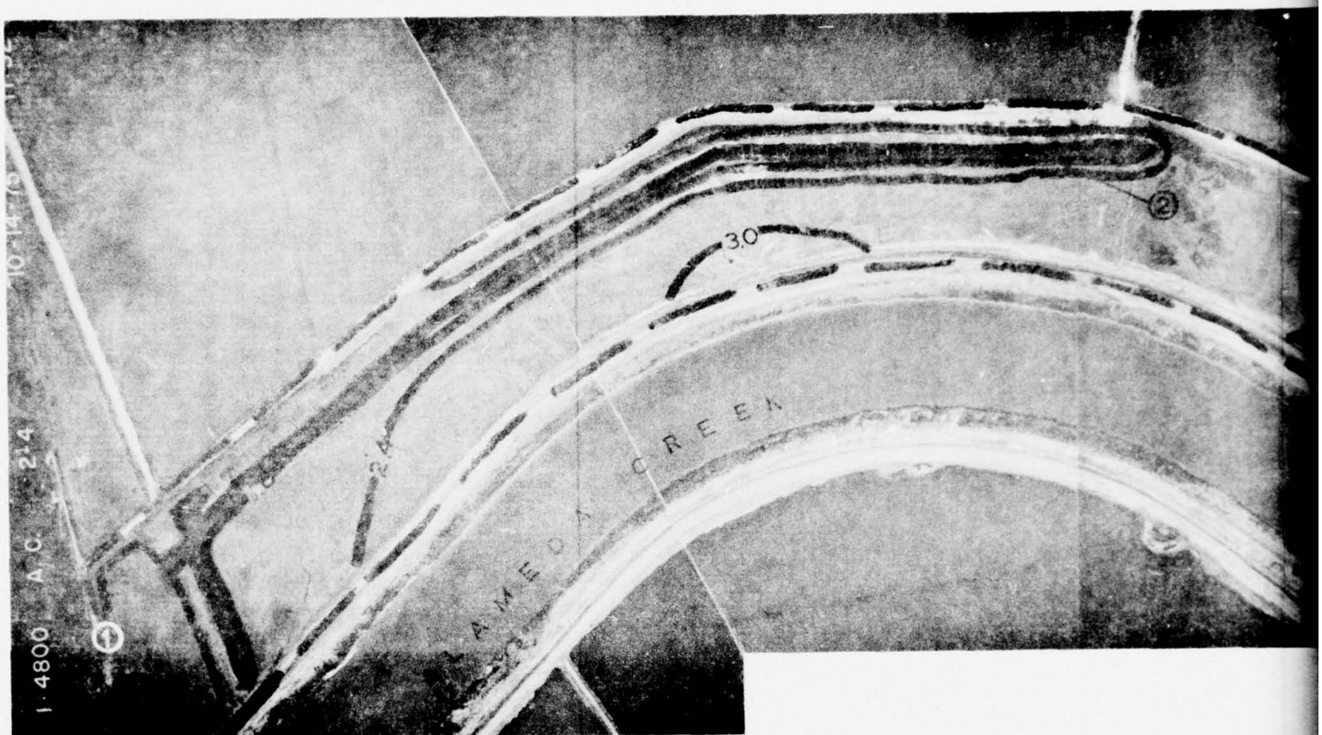


DISPOSAL POND – ALAMEDA CREEK FLOOD CONTROL PROJECT – APRIL 1974

(Five months after the conclusion of disposal operations.)

①-⑦ Location of hydraulic dredge discharge points.

2.7 Contour lines. Elevation in meters, MLLW.



DISPOSAL POND — ALAMEDA CREEK FL

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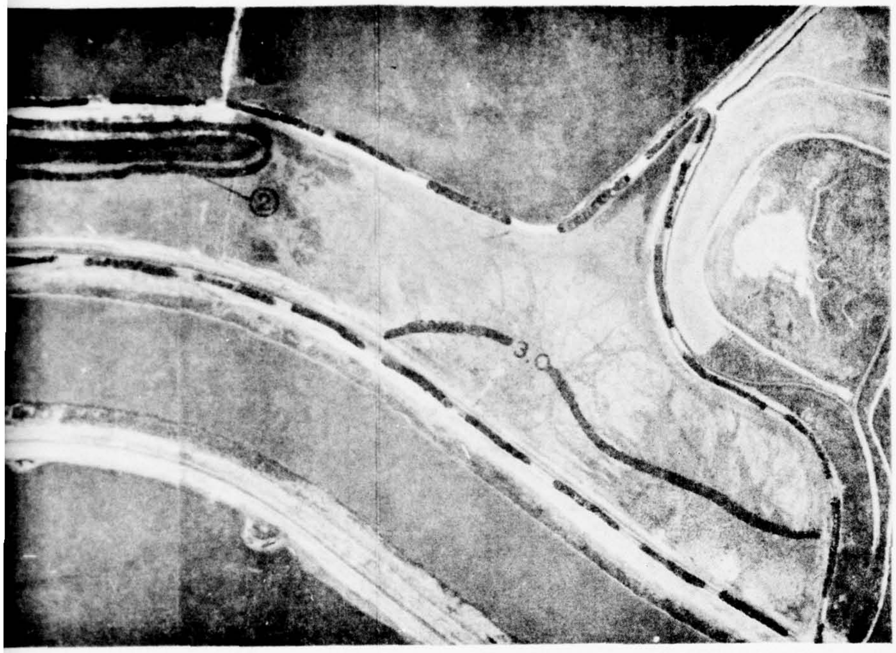


OSAL POND — ALAMEDA CREEK FLOOD CONTROL PROJECT — OCTOBER 1975

) Location of breach in dike.

) Artifically constructed intertidal slough.

2.7 Contour lines. Elevation in meters, MLLW.

PHOTO 8

"The question of appropriate size of the tidal inlet to a marsh can be placed in perspective by considering the consequences of errors. If the inlet is not sufficiently large in cross section, flood currents many be unable to carry enough water into the marsh in a short enough time to provide the desired time of submergence for marsh plants. If the inlet is too large, tidal currents within the inlet will be sluggish and accretion will probably result, until an equilibrium flow area is achieved. At this equilibrium flow area, tidal currents will attain a natural self-cleaning velocity for the materials on the bottom. It would therefore appear that a very large inlet is the preferable error. On the other hand, consideration of the excavation cost and the amount of overburden to be disposed of indicates that the channel should be made just large enough to maintain a self-cleaning tidal current velocity from the beginning.

A review of the literature has led to some relevant facts in determining proper inlet areas and velocities:

> The equilibrium flow area of an inlet depends to a minor extent, if at all, on the grain size distribution of the bottom materials (O'Brien, 1969).
>
> The mean maximum velocity for a wide variety of tidal inlets in America and in Europe is remarkably consistent among locations: approximately 1 meter per second (Bruun, 1967).
>
> Velocity averaged throughout the tidal cycle in a wide variety of tidal inlets has a wider range, but is still fairly consistent among locations: 0.54 to 0.97 meters per second among 11 inlets on the Pacific Coast, Gulf Coast, and Europe (Bruun, 1967).

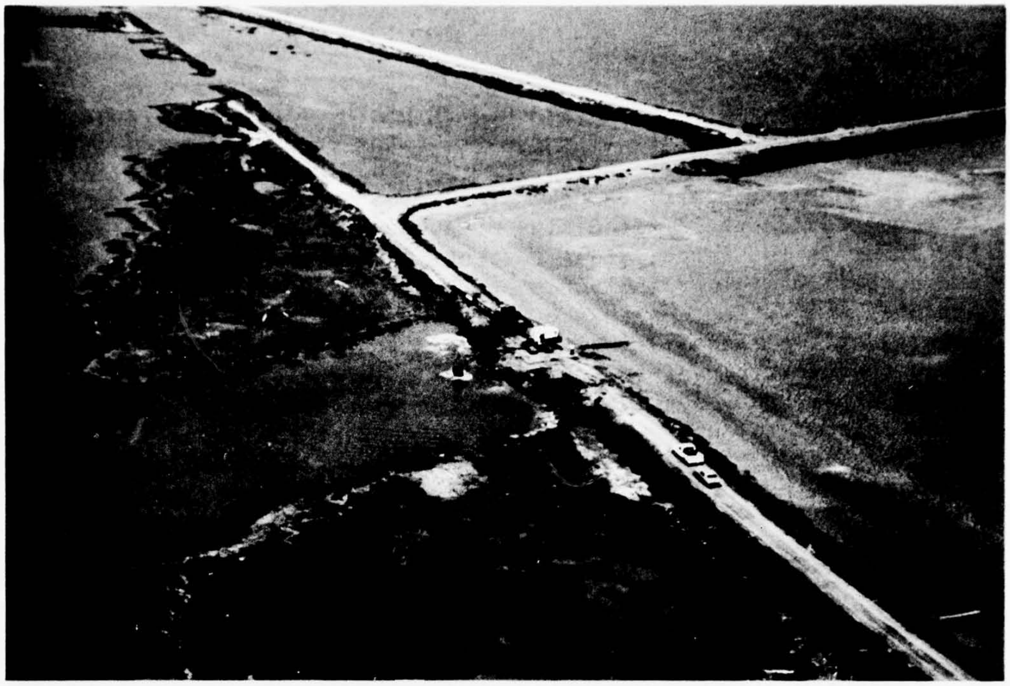
These observations indicate that the inlet should be designed to produce these velocities according to the continuity relationship Q=vA, where

Q = Tidal prism of the marsh (calculated from elevation and topography) divided by time from slack to slack (~1/2 of tidal cycle)

v = Design average velocity (say 0.6 meters/sec)

A = Inlet area."

The bayward dike at the Alameda Creek marsh development area was breached in October 1975 (Photos 9 & 10). Using the above inlet design formula it was calculated that the required breach width should be approximately 30 meters. Observations thus far indicate that the breach was adequate.



BREACHING OPERATION IN DISPOSAL POND. (OCTOBER 1975) PHOTO 9

BEGINNING OF TIDAL CIRCULATION IN DISPOSAL POND AFTER BREACHING.
(OCTOBER 1975) PHOTO 10

COSTS ASSOCIATED WITH THE CONSTRUCTION OF MARSHES

Site Aquisition. The primary usage of low-lying diked lands adjacent to San Francisco Bay is for agriculture and salt production. The estimated cost (purchase not concluded) of acquistion of the Alameda Creek disposal pond is approximately \$2,000 to \$2,500/hectares. Taking the Alameda Creek disposal pond as an example and considering that 535,000 m^3 of dredged material were placed in the disposal pond, the cost per cubic meter attributable to land acquisition would be approximately \$0.17 to $0.21/m^3$. It should be noted that site acquisition cost will vary depending on location, site topography, and the depth of fill.

Site Preparation. Site preparation costs will vary greatly from one area to another. Costs will depend upon the existing elevation of interior dikes, the dimension of the breach in bayward dikes required to maintain tidal circulation, and the amount of additional excavation required to assure drainage of the disposal area. In conjunction with the Alameda Creek project, interior dike revetment, excavation for drainage, and dike breaching were performed. The approximate costs associated with this work base on September 1975 price levels, were as follows:

Dike revetment	\$50,000
Drainage	\$10,000
Dike breaching	\$20,000

Site preparation in this project was approximately \$80,000 (contracting costs not including engineering, design and supervision) or about \$1,750/hectare. At 12,000 m^3/hectares (535,000 m^3/45 hectares), costs attributable to site preparation were about $0.15/m^3$.

Dredge Material Transport.. Dredging and transport cost for the Alameda Creek marsh development project was approximately $\$1.60/m^3$ (contract costs only) at September 1975 price levels. On the basis of area, the dredging and transport cost amounted to \$19,000/hectare. The dredge material transport costs for this project were relatively low due to the close proximity of the dredging and disposal sites.

Planting

As previously discussed, seeding of cordgrass costs an estimated \$3,000/hectare. If the entire pond at Alameda Creek were planted with cordgrass, the total cost would be approximately \$135,000. Considering that the pond accomodated 535,000 m^3 of dredged material, the costs of

the project attributable to planting would be about $\$0.25/m^2$. Table 8 summarizes the acquisition, site preparation, disposal and planting costs associated with the Alameda Creek marsh development.

TABLE 8

CONSTRUCTION AND PLANTING COSTS FOR ALAMEDA CREEK MARSH DEVELOPMENT
(September 1975 Price Levels)

OPERATION	COSTS PER CUBIC METER	COST PER HECTARE
Site Acquisition	\$ 0.20	\$ 2,250
Site Preparation	0.15 1/	1,750
Dredging and Material Transport	1.60 1/	19,000
Planting	0.25	3,000
Total Costs	\$ 2.20	\$26,000

1/ Contract costs only, not including costs for engineering and designs, and supervision and administration.

Summary.

As indicated by the Alameda Creek example, marsh development may be economically practical when used upon a case by case basis. The alternative is particularly attractive for small dredging projects which are located near suitable diked low-lands.

Water Quality Control During Disposal Operations. As previously noted, hydraulically dredged material slurries contain 80 to 90 percent water, which must be decanted during disposal operations. This is usually accomplished with the use of weirs. Because of the fine-grained nature of Bay sediments, clarification of the supernate waters in disposal areas before release back into the Bay must be considered. It has been found that in fresh water the clay particles in dredged material may remain suspended for long periods of time. However, saline waters cause a flocculation of clay particles and the clarification of supernate waters occurs very rapidly (Dredge Disposal Study, Appendix M-Dredging Technology). The threat of water degradation during the disposal operation can be alleviated for the most part if the salinities of return waters are high. When dredging operations are located near freshwater tributaries, dredging should be timed to correspond with periods of low freshwater inflow. It is important that residence times for water within a disposal area be kept to a minimum. Contrary to what one would expect, the quality of the supernate water in a confined disposal area is degraded when lengthy settling periods are allowed. Windom (1974) has observed that "metal concentrations in the water column initially are depleted due to scavenging, presumably by the precipitation of hydrated iron oxides. After equilibration of the deposited dredged spoil, some of the accumlated metals are released to the water column again, reaching ambient levels or higher. This process takes on the order of a few days to occur". In general, waters decanted from disposal areas will be high in oxygen but during certain seasons may be more turbid than receiving waters.

Mosquito Control. Two species of mosquitoes inhabit salt marsh areas in San Francisco Bay. Both types (*Aedes squamiger* - Gray salt marsh mosquito and *Aedes dorsalis* - Salt marsh mosquito) are rated high in willingness to bite man and have been a problem to bay area residents in the past. Local mosquito control districts in San Francisco Bay now keep populations well under control. After Pond 3, Alameda Creek Marsh Development Area, was opened to tidal action in October 1975, the Alameda County Mosquito Control District surveyed the area for potential mosquito breeding problem areas. Table 9 summarizes the findings of this survey.

TABLE 9

ALAMEDA CREEK MARSH DEVELOPMENT DISPOSAL POND
(MOSQUITO CONTROL PERSPECTIVE)

MARSH CHARACTERISTICS	ESTIMATED AREA (HECTARES)	POTENTIAL FOR MOSQUITOES	PREVENTIVE AND REMEDIAL MEASURES
Low ground, subject to daily tidal inundation	15	None	
Higher ground, subject to extreme high tide inundation. Forms isolated pools.	3	High	Ditch to allow daily tidal action.
Higher cracked ground. Cracks subject to extreme high tide influence.	21	High	Disc cracked ground.
High ground may be flooded by some extreme high tides. Cracked ground may hold storm water.	4	Moderate-High	Disc, Ditch.
High ground, above extreme high tides. Some cracking. May hold storm water.	11	Low	Inspect. Disc if necessary.
Higher ground subject to extreme high tides, but self draining.	6	Low	Inspect

The creation of additional salt marshes need not enhance the local mosquito populations, because intertidal areas which are well drained do not provide breeding conditions. However, as indicated by the above survey some maintenance of drainage patterns will be required to avoid ponding of water on the surface or within the cracks in the disposal area.

Marsh and Heavy Metal Cycling. Windom (1973) and Dunston (1973) performed a study of metal movement through the estuarine system and metal association in marshes. Mercury, iron, copper, and manganese were delineated as to their pathways in the estuary using a material balance approach. They found that metals from river inputs accumulated in deposits on tidal flats. Three of the metals (iron, copper, and manganese) were retained in the marsh sediments. Mercury, however, moved into plant tissues and concentrated many times higher than sediment levels. The mercury concentrated in plant tissues ultimately moved out of the estuary in the form of organic detritus evolved from decay of the marsh plants. Heavy metal uptake in plant tissues was not measured in the present study. However, a significant increase in iron, lead, and zinc in marsh elements was observed in the test planting area during the second growing season.

CONCLUSION

The planting and monitoring of replicate test plots in an unconfined area has affirmed that dredged material is a suitable substrate for the propagation of intertidal vegetation in San Francisco Bay. The natural invasion of cordgrass to barren substrates appears to be very slow and the use of artificial propagation techniques seems warranted. All the cordgrass propagation techniques tested speeded the process of revegetation. The use of direct seeding is the most promising planting method as it requires the least investment in labor, facilities, and equipment. It is estimated that the seeded test plots will reach full productivity mid-way through the third growing season. Based upon a review of existing literature and observations made during planting studies, it is concluded that the planting of cordgrass is practical between the elevational limits of MHHW and MTL and within the salinity ranges from 10 to 40°/oo. It is doubtful that the artificial propagation of pickleweed is warranted. Because of its weedy nature it rapidly invades barren substrate without encouragement, particularly when adult plants of the genus are located in the general vicinity. There are approximately 270 km^2 of potential marsh development areas along the shores of San Francisco Bay. Theoretically, 200 to 250 million m^3 of dredged material could be accomodated if total utilization was made of the marsh development alternative. Study observations to date indicate that within practical limits, an appropriate marsh topography can be established with available equipment and existing dredging technology. The marsh development alternative may be economically practical for use in small dredging projects which are located near suitable diked lowlands.

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INCLOSURE ONE

SAN FRANCISCO BAY AND ESTUARY DREDGE
DISPOSAL STUDY

MARSH DEVELOPMENT STUDY

PHASE ONE - PRELIMINARY INVESTIGATION

by
Dr. Herbert L. Mason
(S.F. Bay Marine Research Center)

MARSH STUDIES

SAN FRANCISCO BAY AND ESTUARY DREDGE DISPOSAL STUDY

USE OF DREDGED MATERIAL FOR MARSHLAND DEVELOPMENT

by

Dr. Herbert L. Mason
Project Director

Submitted by

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SAN FRANCISCO BAY AND ESTUARY DREDGE DISPOSAL STUDY

USE OF DREDGED MATERIAL FOR MARSHLAND DEVELOPMENT*

by

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San Francisco Bay Marine Research Center, Inc.

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* A study conducted under Contract Number DACW07-74-C-0008 for the U.S. Army Corps of Engineers - San Francisco District Office.

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USE OF DREDGED MATERIAL FOR MARSHLAND DEVELOPMENT

I. Introduction

A. The Problem

The disposal of dredge spoil has been a perennial problem. There are many who hold that it raises more problems than it solves. Objectors to disposal sites on land point to its general sterility and the long time required for it to develop a vegetation cover as well as to the change it creates in the ecology of the area covered. Objectors to its disposal at sea point to the destruction of established habitats by covering with spoil and the loss of considerable area of natural habitat and hence loss of productivity of the waters.

There is another problem demanding attention, namely our salt marshes. These have been the victims of encroachment by many human activities. Salt marshes have provided an area of cheap land that has been filled and rendered habitable by man or useful to him in any of several other ways. They have provided borrow materials for dikes and roadways with the consequent loss of the marsh habitat. They have been the victim of the widening and deepening of near shore channels and canals. As a consequence the area of salt marsh on San Francisco Bay has been seriously decimated with a consequent loss of productivity of adjacent waters. Figure 1 is designed to tell the story of our diminishing salt marshes.

It so happens that salt marshes are important to the productivity of the waters they border. Their plants are among the primary producers

of food resources generated in aquatic food chains of estuaries, bays and oceans as they transform energy from the sun through photosynthesis, and store it in plant materials to be eaten by countless kinds of organisms, each of which in turn is the food for some higher type of organism. Thus they enter into the food resources of our fisheries and of our game birds. To the extent that this is the case our fisheries depend upon the productivity of the salt marshes. It is held with good reason that much of the loss of the productivity of our present fisheries can be correlated with the loss of salt marsh area.

It is now clear that some of these salt marsh plants may play an important role in transforming the typically anaerobic soils of bays and estuaries into aerobic soils and thereby rendering these soils habitable to many benthic organisms that also enter the food chains of higher organisms. Spartina, the cordgrass, for example, was found to be growing on soils that did not have the characteristic hydrogen sulfide odor common to many anaerobic bay muds. One however need not dig very far to find this odor. Indeed one need only go to the soils into which the Spartina is sending its new rhizomes. Cutting into the soil we observed that characteristic iron oxide color which indicated the presence of aerobic iron bacteria that were oxidizing the iron present in the soil. This color was in the vicinity of the older roots and rhizomes (underground stems) of Spartina. We next observed in the anatomy of Spartina plants the presence of an extensive tissue called "aerenchyma" by the botanist, that provides gas passage from the roots through the rhizome system and the upright stems and the leaves. Thus there is continuity for passage of air from the atmosphere through the stomata of leaves and stems into the aerenchyma passages down to the root tips. The cells

of this aerenchyma are very succulent. Indeed they are so succulent that the rhizomes which are made up chiefly of aerenchyma are sought after by geese during the winter months when other grazing is sparse. Atmospheric air contains oxygen. Oxygen is also given off by the plant as a consequence of photosynthesis. Some of this photosynthetic oxygen may also find its way into the aerenchyma.

We therefore have developed the hypothesis that Spartina is important to the oxygenation of salt marsh soils and have designed experiments to test this hypothesis. These experiments are now under way. A detailed study of the physiological anatomy of Spartina is also under way.

As pointed out above, the area occupied by salt marsh has steadily decreased since white man colonized California. What we have left is only a very small portion of what we once had. As a consequence the productivity of the bay has become so reduced that every other force that tends to reduce populations does so more and more effectively on reduced numbers. For example when populations are low it is very easy to overfish. Disease wreaks greater havoc percentage-wise on small populations than on large populations. When food is scarce predators intensify their search.

It has been reasoned that by a careful placing of dredge spoil, salt marsh plants could be planted upon it in an operation that would at once provide a place for the dredge spoil and initiate the successions of organisms in a way that would build a salt marsh. It is hoped thereby to increase the area of salt marsh and build toward a more productive bay. As easy as this may appear to be it is not without its problems.

Our western salt marsh plants, especially Spartina foliosa, have proved to be refractory to efforts to study seed production and germination.

Over much of the marsh area either no seed is produced or very little seed is produced. It is necessary to search out adequate sources of seed. When one finds it there are no machines designed to harvest and thresh seed in the marshes. It must be done as effectively as we can with what we can improvise. Seeds must be stored in cold salt water. Because of these difficulties most Western researchers have assumed that artificial salt marsh production was impractical. We have found no evidence in Western literature that they tried planting cuttings of the plants.

On the other hand, on the Atlantic Coast research continued employing cuttings and delving further into the problems of seed germination. (Woodhouse, Seneca & Broom, 1972). They found that cuttings could be applied directly to their marshes with good success. They found also that Spartina seed needed soaking in freshwater in order to begin the operations of germination and that a two month period of "after ripening" was required from harvest before germination, although this could be materially shortened by soaking for two weeks in freshwater. Their soils are firmer than ours and can be traversed with conventional or adapted agricultural machinery during low tide.

One cannot assume that two species in the same genus will behave alike to efforts to bring them into cultivation. Since our plants are different from those along the Atlantic Coast it was deemed essential that we seek to learn something of propagation methods for ours.

B. Objectives of Our Study

Basically our objectives were to learn all that we could about the artificial propagation of Spartina foliosa and Salicornia pacifica and their local genetic variants. This meant the testing of different methods to induce rooting of cuttings of the plants and testing all of the methods

that we could devise in the hope of inducing the germination of seeds. Immediately so many possible combinations of treatment presented themselves that it became necessary to make a selection of a very few which we thought might be most likely to succeed. Out of a possible combination of 196 soil types as cutting media we selected 4 to test. All of the four yielded a fairly high level of success but some slightly better than others. Since, because of time, what we were after was success we maintained the study sufficiently flexible to redirect our attention into the most promising leads.

The plants produced were to serve another objective, namely to supply propagules for a second phase of the study, a pilot project on the dredge spoil that it is hoped would be planted. A plan for this second phase is also a part of our objectives.

We were aware that if we left the dredge spoil long enough to be repeatedly covered and uncovered by tidal waters it would at long last possibly many years develop a marsh. However in the meantime it would lose much of its substance back into the channels where it was not wanted. Thus our objectives at length include developing a root system in the dredge spoil to stabilize it as soon as we can.

Although we employed both Spartina and Salicornia we were especially solicitous of Spartina, first, because of the challenge it presented, second, because of the role that it plays in the salt marsh, and third, because of our judgement that if we could get it started successfully on the dredge spoil, Salicornia would establish itself in the marsh very quickly. Being a weedy type of plant like many other members of its plant family it misses very few opportunities to colonize. There are few spots in a natural marsh that it does not quickly enter except in the

deeper levels of the intertidal water. The *Spartina* would prepare the soil upon which the *Salicornia* would follow. However at this stage of our study we could not neglect the *Salicornia*. But (as work proceeded) it was *Spartina* that repeatedly generated new implications suggesting new lines of approach.

In summary, the objectives of our study are 1) to explore the propagation methods of certain salt marsh plants; 2) to explore the biotic and physical features of a typical salt marsh to serve as a baseline toward which to direct achievement in building a salt marsh; and 3) to explore the use of the plants developed in this preliminary study in a pilot study of Pond 3 which is filled with dredge spoil from the Alameda flood control channel in southern Alameda County, California.

C. The Nature of the Approaches

The sequence to the approaches of our subject were dictated by the local biological calendar. At the time the project was activated seed was not yet ripe and winter dormancy was soon to prevail. As a consequence our attention was first directed to making cuttings of the plants we were to employ. This was followed by a field review of salt marsh ecology to serve as a conceptual base in directing our salt marsh construction planning. Simultaneously a literature search was begun to assess the state of knowledge of the subject. Seed did not ripen until well into October so that experimental work on germination had to be delayed. This left a very short time for a major part of the work. It is major because it is to be expected that costs can be greatly reduced if we can rely upon seed for planting.

A literature search was begun and, as we had anticipated, there was very little work reported on California plants. Without exception these

all reported failure to gain successful germinations of *Spartina* seed. A more abundant literature dealing with the problems in the Eastern U.S. and in England reported success, especially that reporting work done in North and South Carolina.

D. Staff

The project was headed by Dr. Herbert L. Mason, Emeritus professor of Botany, University of California, Berkeley who served as Project Director. Dr. Curtis L. Newcombe, Director of the San Francisco Bay Marine Research Center, supervised the zoological work; Mr. John Jackson, M.A., limnologist and a professional horticulturist, supervised the nursery operation; and Professor J. C. Jayne, San Francisco State University, supervised the chemistry studies.

Staff members of the Marine Research Center assigned to the project were: James Jackson, chemist; Geoffrey Wong, M.S., plant pathologist; David Maiero, zoologist; Meigs Matheson, biologist; and Chris Jong, taxonomist. Phillip Henika was in charge of the bibliographic materials. Identification of benthic specimens was facilitated by the reference collection at Marine Research Center and checked by specialists in certain particular groups. We are grateful for oral communications from Dr. Edgar Garbisch of Environmental Concern Corporation of St. Michaels, Maryland.

Special thanks are expressed to Mr. Paul Knudsen, the Corps of Engineers botanist who monitored the project, for his helpful assistance on various aspects of the investigation.

II. The Natural Features of the Site Area

The construction of a salt marsh assumes a normal state whose ecological conditions one seeks to duplicate and whose biota one seeks

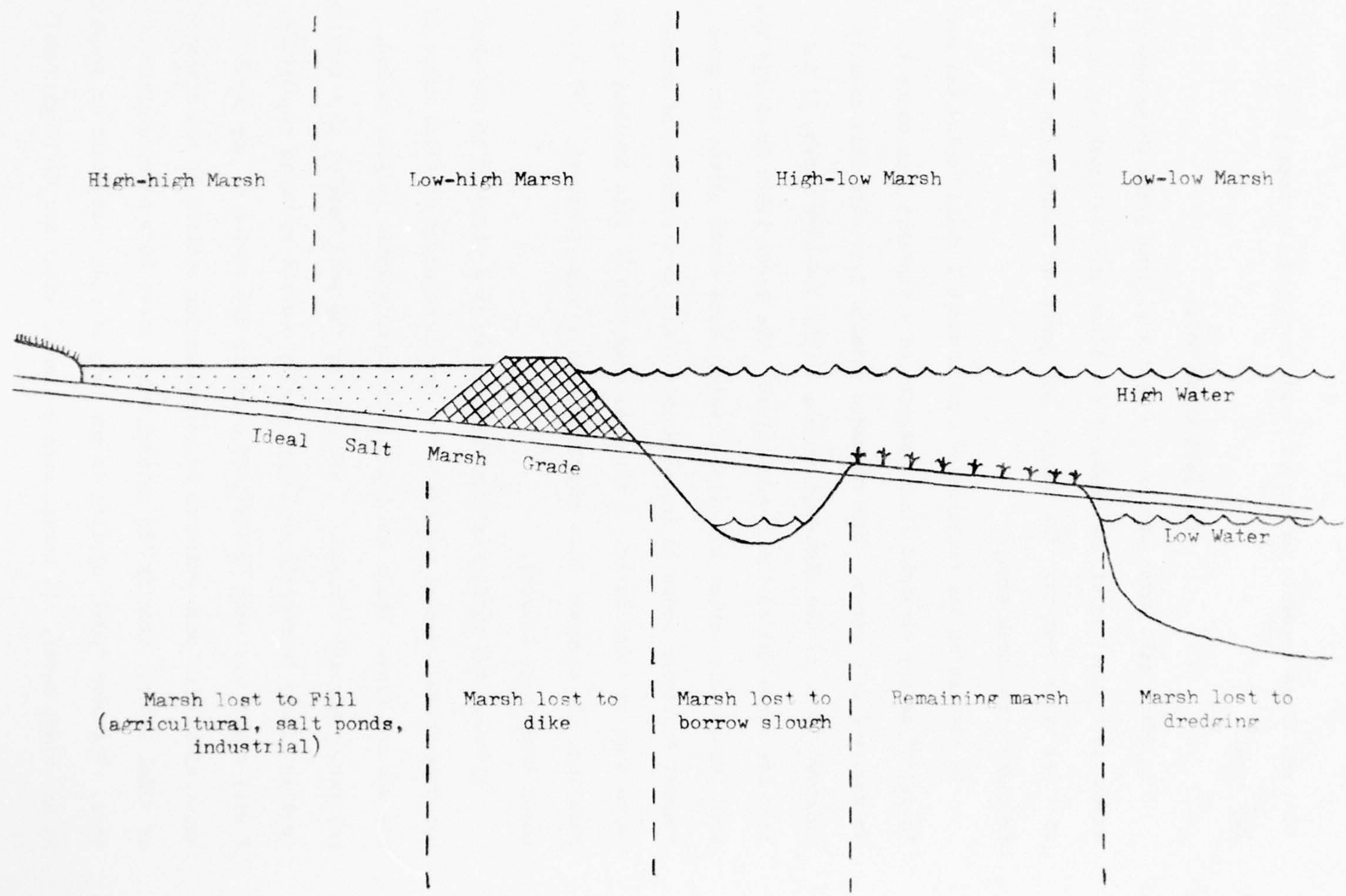
to at least mimic. Our efforts to find such a marsh to serve us as a control encountered many time-consuming problems which we had not anticipated. Most of the problems are a consequence of the impingement of human activities on the salt marshes. The reclamation of land, the construction of salt evaporation pans, the building of dikes and their borrow channels, the construction of highway fills, the construction of duck blinds and duck ponds, the deepening and widening of ship and of boat channels as well as some natural erosion, has enormously reduced the area of natural salt marsh in the San Francisco Bay region. Upon what is left most of the flotsam and jetsam of the bay finally comes ashore to further decrease the area available to salt marsh biota. In some marshes visited it was estimated that as much as 20% of the total area was taken over by such water born trash. Figure 1 is a diagram of how the intertidal area occupied by a salt marsh is reduced as a consequence of the activities of man.

Every seemingly natural marsh that we visited shows some alteration as a consequence of the distortion of its habitat through the activities of man. What is left are fragments of the original salt marsh. Of the four levels of original salt marsh in the intertidal zone rarely is there more than one level left. Occasionally there is one and part of another. Most often the whole marsh has been so distorted that nothing of what is left can be accepted as ecologically typical. Yet there is a salt marsh.

We decided that what we must do is to gain a concept of a typical salt marsh synthesized from what we can find in several different marshes to guide us in our efforts to reconstruct the marsh. For this purpose we began with a conceptual model into which we can interpret what we

FIGURE I

THE SAGA OF THE SALT MARSHES OF SAN FRANCISCO BAY



find and whose segments we can at length verify in various parts of the Bay Area.

The Salt Marsh Model

An ideal salt marsh occurs on a gently sloping plane whose bayward extent is a function of the grade of its plane and the depth and duration of tidal water over it. The steeper the grade the shorter the distance from shore to marsh edge.

In discussing the features of such a marsh I shall employ the word "stretch" as any straight linear segment of a distance from shore to bayward end of a marsh. This distance entails four stretches usually referred to as 1) the high-high marsh, 2) the low-high marsh, 3) the high-low marsh and 4) the low-low marsh. The lower limit is always the area immediately beyond the deepest water where marsh plants can grow. Present knowledge seems to indicate this limit is a function of submergence time to tidal water. I find the sharpness of this boundary to be puzzling. It suggests that something else is also involved. (Pl.II.6 shows three such levels).

Although the surface of our ideal marsh is a plane it is one that has been formed, carved and dissected by the movement of tidal water in its ebb and flow. There are low almost imperceptable ridges, swales, gullies, ponds and sloughs. I will employ the word "swale" as a shallow, usually linear depression at length wholly covered by marsh vegetation. I will employ the word "gully" for a linear depression of any depth whose sides show some evidence of perpendicular cutting by the movement of tidal water. Usually the perpendicular sides have no vegetation on them. The word "pond" applies to any body of open water that is trapped at any tidal level. As ponds, such bodies of water are distinguishable

only during ebb tide. They may, during their existence as ponds, affect the nature of the vegetation that surrounds them. Characteristic stands of *Spartina* often surround them.

The soils will be silts, sands, clays and organics in various states of pureness or of admixture as governed by the sorting and homogenizing events of their depositional history, and the subsequent biology of the decompostion of their organic content. This in turn is a function of the oxygen level of the soils. The inorganic content of the soils will be a function of the kind of rock that has been the geological and physiographic origin of the sediments.

Floristics

Along the margins of San Francisco Bay such a marsh will be inhabited by a very few kinds of plants chiefly genetic variants of *Spartina foliosa* and *Salicornia pacifica*. There will be a few others. The basic geographic pattern of the occurrence of these two dominants will be that of an overlap of two genetic clines in their ecotypic adaptations to the tidal cline of duration of submergence of the marsh floor. The cline will be modified and locally patterned by topographic features and such other features as may determine whether a pure stand or some admixture of populations is selected by the habitat. As is the case with all other vegetation in California we can expect certain anomalies that seem inconsistent with the accepted model. As employed above the word "ecotype" is to convey the meaning of a genetic type selected by the local segment of the selecting condition. I do not employ the word "adapted", it seems to say more than I wish for it to. My point is that the environment selected a race whose ecological range was a product of biogenetic events that may have been independent of

the precise conditions that selected the progeny. Some call this "pre-adaption" whose orthographic roots lay in the concept of adaptation and places us back in the same rut. It is sufficient to think of the problem in terms of natural selection.

The floristics dominated by such an overlap will display a low-low marsh of almost a pure stand of Spartina foliosa. On the other hand the high-high marsh will be largely of Salicornia pacifica with some overlap of marsh border halophytes and some extension of the high marsh races of Salicornia beyond the tide control. I have seen only an occasional Spartina at this level. Between these two intertidal marshes will be an extensive area of overlap containing quite an elaborate mosaic of vegetation when considered in terms of the relatively few elements that contribute to its differentiation. Basically it is made up of a rather uniform race of Salicornia pacifica, a race of Spartina foliosa with more slender culms than that in the low-low marsh and much less densely spaced; finally there are rather extensive patches of Jaumia carnosa (Pl.II3.4). Any other kinds of plants are so rare as to be inconsequential for our objectives. The very obvious mosaic patterning is a consequence of various combinations of these three kinds of plants as they occur in pure stands of each as well as in any combination of the three occurring together in mixed stands each combination of which, because of the growth form of the components, presents a visually distinctive appearance. The Spartina is erect and slender, Salicornia is spreading rarely more than half as tall as the Spartina while the Jaumia in pure stand forms a thick mat of prostrate silvery stems extending under and among the other kinds of plants making the mixed stands clearly differentiable at a glance by its presence. Thus there are seven possible combinations of the elements

to influence the mosaic while differences of density of each will influence the shading of one into the other.

Such a marsh, when viewed as a whole, reminds one of an elaborately sculptured rug. It is the level of salt marsh least vulnerable to human encroachment, hence it with the low-high marsh is what most people know as "salt marsh". That is to say that there is more of these left than of the marsh of any other level.

The low-high marsh differs from the high-low marsh largely in much lower concentration of Spartina foliosa. This is clearly visible to the eye. Salicornia very clearly dominates most of the area with Spartina confined largely to the swales and gullies. Jaumia is also much less frequent in dense stands although one encounters single strands frequently. The Salicornia at this marsh level is still quite uniform in type although it does increase in diversity as one approaches the high-high marsh.

The mosaic effect of the low-high marsh is much less conspicuous to the eye and, because of the dominance of Salicornia, is largely a consequence of the topographic selection of Spartina and the topography of the drainage pattern of the marsh. Thus the diversity of the mosaic provides another ready visual distinction between the low-high and the high-low marsh. It must be born in mind however that the clinal nature of these variables will present many vexing problems in intermediate areas.

A typical well developed high-high marsh is probably the rarest of all salt marshes today. It occupies marsh levels that are the cheapest to reclaim, and that is precisely what has happened to it. It also is the recipient of the greatest amount of flotsam and jetsam and is often in great disarray.

The high-high marsh is dominated by a highly variable population of Salicornia such as suggests considerable cytogenetic activity. Most of the plants are clearly related to S. pacifica; however there are also several kinds whose members are annuals along the shore line borders of the high-high marsh. The perennial, S. pacifica is here represented by two distinct types, namely a low spreading type that may or may not root along the prostrate stems and a virgately erect type with stout stiff stems. There are many seeming intergrades between them. In addition like many other members of their plant family, both types are very "weedy" in their ecological response which allows them to spread vigorously into disturbed land. Hence we find them clambering up dikes and frequent along roadsides and paths near the marsh.

To say that a typical high-high marsh is very rare is not to imply that its members are on the verge of extinction. This weedy habit will preserve them for a long time to come as they move into every untidy situation along the shore line.

As would be expected there is considerable infiltration of marginal halophytes into the high-high marsh, yet in our area only Atriplex hastata seems to have the potential to some day move into the salt marsh community as a regular member. Several times I have seen individuals with leaves so succulent as to appear bloated. One of these I found even in the low-low marsh among tall Spartina near the mouth of Sonoma Creek. This implies a capacity to endure inundation for considerable time, twice each day.

The best stands of low-low marsh known to me are along the southwest shore of the bay and at the mouths of streams flowing into the north shore of San Pablo Bay as well as some good stands on the south side of Suisun Bay and in the Suisun Marsh.

There are some good stands of the high-low marsh along the southern Alameda and northern Santa Clara county shores.

There is a long stretch of low-high marsh along the north shore of San Pablo Bay that may at least in part, be a natural reclamation of the marsh from abandoned agricultural use, and the infiltration of salt into the soils. A small low-high marsh may be seen along Highway 17 between Albany and El Cerrito.

As mentioned above one can expect anomalies in any vegetation type in California and we do find them in the salt marshes. A marsh occurring on the intertidal headlands where the bay is cutting deep into the marsh in southern Alameda County in a position one would expect a low-high marsh, is a mixed stand of a decumbent Spartina whose culms are 2-3 dm. long associated with a depauperate, ground hugging Salicornia (Pl.I,4;II,5). Rhizomes of the Spartina seem concentrated in the upper 2 dm. of the soil although a few go deeper. It suggests S. patens of the Atlantic Coast but is very clearly related to S. foliosa. The Salicornia was too far along toward winter dormant condition to provide adequate material for study. An occasional strand of Jaumia was seen. These plants matured fully three weeks ahead of their counterparts in the high-low marsh. The soils seem a lighter color than adjacent soils and has more clay in it. The soil surface wherever we have seen these plants, slopes toward the bay. An almost imperceptable ridge separates the stand from the high-low marsh. The ridge in one or two spots does get high enough to support Grindelia. This suggests that tidally the marsh is fairly high. We will check its soils for calcium-magnesium ratio because several kinds of floristic anomalies in California occur on soils where the calcium is bound by the magnesium and rendered unavailable to the

plants. Only plants that have the power to break these bonds can grow on such soils. Serpentine soils and those derived from granodiorites and dolomites are common offenders in this respect. Much of the sediment of the south end of the bay came out of the Santa Clara Valley which is flanked on both sides by extensive outcrops of serpentinized rock. Some of the main tributary canyons of the headwaters of Alameda Creek cut through massive serpentinized rock.

Plant Succession

Plant succession in the salt marsh is far more complex than the limited numbers of kinds of plants would lead one to suspect. This stems from the fact that we speak of the salt marsh as one yet no one kind or race of plants occurs throughout the entire salt marsh. For example Salicornia occurs in the upper three-fourths of the soils of the tidal interval while Spartina is confined to the soils of the lower three-fourths. Of the flowering plants Salicornia is the invader in the high-high marsh with border halophytes following in the succession. There is no Spartina. In the low-low marsh Spartina is the first seed plant and usually the only seed plant to invade. There is no Salicornia. In both the low-high and high-low marshes evidence at hand seems to point that Spartina is the pioneer with Salicornia the successor. In the high-low marsh they remain in about equal abundance. In the low-high marsh Salicornia tends to take over dominance with Spartina in depressions.

Prior to Salicornia on mud flats of low-high and high-high level we have observed the algae Ulva and Enteromorpha. We have also observed Salicornia entering where these were present. Where they were absent there was no Salicornia. This suggests that the real pioneers on such mud flats are the algae Ulva and Enteromorpha followed by Salicornia

and in turn by marsh border invaders such as Atriplex hastata ssp. and A. semibaccata. It also suggests that Ulva and Enteromorpha may play a role in the oxygenation of the surface soils. Jaumia is abundant in our experience only in the high-low marsh, less common in the low-high marsh with occasional strands in both the upper edge of the low-low marsh to the high-high marsh. Jaumia seems to have the greatest tolerance span for duration of submergence of any of the salt marsh plants of our area.

Predators and Diseases of Salt Marsh Plants

During our field studies we noted several herbivores, mainly brush rabbits, jackrabbits and ground squirrels in the salt marshes during low tide. Although we did not observe them actually feeding, we did observe Spartina plants that had been damaged in a manner suggestive of herbivore activity. Culms had been cut off and miscellaneous fragments of leaves and culms were on the ground. On two occasions we found small piles of culm fragments about ¼ inch long each with rodent droppings in the vicinity. These gave the appearance of muskrat droppings. However, we saw no muskrats. Song sparrows were observed feeding on seeds of Spartina in mid and late October.

In stands of Spartina we noted rare to abundant infestations of Spartina with ergot (Claviceps purpurea (Fr.) Tul.) which Mr. Geoffrey Wong, our plant pathologist, identified for us and suggested the following details of its life history. Claviceps purpurea is the common ergot on rye and sorghum as well as many other grasses. Although to our knowledge this is the first record of ergot on Spartina foliosa, it has been reported on S. alterniflora Lois. of our Atlantic Seaboard; S. cynosuroides (L) Roth. from New York State; S. gracilis Trin. from Saskatchewan; S. patens (Ait) Muhl. from Maryland; and S. pectinata Lk. from the Great Plains States.

We see evidence of the disease as a large purple to black structure called a "sclerotium" which grows from a flower where one might expect a seed. At maturity the sclerotium may be from 0.5 to 1.5 cm long. It falls to the ground where it probably becomes covered with silt or detritus and overwinters in this state. Based on the fungus' life cycle on other host plants, during the next growing season as temperatures rise, the sclerotia send up one or more stromata through the surface soil. These rise about 1.5 cm high. They appear as a round head of tissue on a slender stalk. Both head and stalk are flesh colored. The surface of the stroma has many pocket-like fruiting bodies called "perithecia". From the bottom of each perithecium arise many tubular sacs called "asci", each containing eight ascospores. These are discharged into the air when ripe, each in a tiny drop of fluid, at a time when the Spartina are in flower. If an ascospore lands on the flowering parts, it germinates to form hyphae, which invade and grow upon the reproductive structures of Spartina. On this mycelium, consisting of innumerable strands of hyphae, specialized stalks form called "conidiophores". These conidiophores produce asexual spores which aggregate in honeydew-like masses and become dispersed by rain, insects or birds to produce secondary infections. During early fall a new sclerotium is formed in each infected flower.

Although there is evidence that seed production may be significantly reduced by the presence of ergot, on the practical side, in plants like Spartina foliosa where seed production is rare, the seed collector is guided to a stand where seed is being produced by the obviousness of an infection of ergot.

Benthic Studies

The benthic studies were organized and carried out to completion by Mr. David Maiero with the assistance of Miss Megis Matheson and others.

The benthic work entailed two major tasks namely, to characterize the site at Pond 3 both before and after placing the dredge spoil and the site from which the dredge spoil was taken, and to characterize the benthic populations of typical salt marsh communities in the Alameda Flood Control area. In conjunction with these benthic studies soil samples were collected for chemical analyses.

Methods

All samples were primarily screened using a large, rectangular #30 screen (28 meshes per inch, 0.595 mm openings). Plant parts and rocks were removed and rhizome-soil masses broken down eliminating the bulk of loose soil. This pre-sort using s small screen size seemed to reduce the chance of breakage occurring with the bodies of large polychaetes and oligochaetes. A #10 sieve (1.8 mm openings) in combination with a #35 sieve (0.51 mm openings) was used to complete the sample sorting.

Immediately after sieving the samples were fixed in 10% formalin for four hours followed by preservation in 70% isopropyl alcohol.

Pond 3 Before Fill

Area Description

The topography of Pond 3 before filling was a flat basin (ex-salt pond) surrounded by levees having a slightly higher eastern end (land-side) sloping downward to the lower western end (bay-side). Approximately two-thirds of the western end (bay-side) of the pond was found to be influenced by tidal action. Since all of the water entered the pond through two small openings in the dike (northwestern corner), wave action or strong tidal surge was absent.

Four study sites were chosen, the distance between each measured using an automobile odometer. Beginning at the most southwestern corner

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of Pond 3, eastward station distances are

Station 1 - 0.3 mile
Station 2 - 0.4 mile
Station 3 - 0.7 mile
Station 4 - 1.3 mile

Station Description

Station 1 - The top 10 cm of the substrate at Station 1 consisted of very black, silty mud with a strong sulfide odor. No macrophytes were present. Four amphipods (family Gammaridae) were found along with a total of 20 pelecypods represented by *Macoma* sp. and *Mya arenaria*. This was the only site at which living pelecypods were found.

Station 1 Cores - Core A yielded three empty gastropod shells after sorting. Core B (taken approximately 15 cm west of Core A) had to be literally "crunched" through the substrate. This core contained 154 empty gastropod shells of a turriform type. The majority of the remains are believed to be of the genus *Tachyrhynchus*. The interesting aspect was the definite interface between the area of heavy gastropod remains and that in which gastropod remains were completely lacking.

Further exploration of the site using a soil core showed concentrated snail remains to extend approximately 3 meters west of Station 1, ending as abruptly as it started. The remains were located approximately 15 cm from the surface and extended as a layer for an additional 10 cm. The snail remains were mixed into the firm grey clay soil supporting the upper anaerobic muds. A previous dike or mound may have bordered the area drawing the lines of inhabitation to a one time flourishing gastropod population. It should be noted that Pond 3 contained no living observed or sampled gastropods of the turriform type.

Station 2 - By visual examination Station 2 appeared to be the most productive. The banks of the adjacent levee supported a heavier *Salicornia* growth than was found in the adjacent areas. Diatom growth was evident along with small bunches of stationary *Enteromorpha* sheltering a population of Amphipods. At mean tide the sampling site was covered by approximately 15 cm of water. This area was randomly sampled at two sites, labeled Stations 2A and 2B. Sample 2A was taken at the lowest watermark and Sample 2B at the highest watermark in order to compare possible differences in any burrowing organisms found in adjacent areas at two different tidal levels.

Transient organisms were the only forms found at either Station 2A or 2B. Both sites contained a small number of amphipods (suborder Gammaridea) and ostracods. Because of constant submergence, Station 2A yielded five times as many arthropods as Station 2B.

The substrate at both sites consisted of a thin layer of dark grey mud (approximately 10 cm) resting upon the same grey clay found at Station 1. In comparison with Station 1, a definite decrease in sulfide odor was noticed.

Station 2 Core Composites - None of the four cores yielded any living macroinvertebrates. Deteriorated pelecypod remains and a few Foraminifera (2A Core) were the only trace of biological inhabitation.

Station 3 - A change in surface "texture" and color was noted when sampling Station 3. At the time of sampling (mean tide level) the site was covered by approximately 30 cm of water. The substrate consisted of finely particulate soil mixed with a heavy amount of plant detritus. The detritus layer extended the vertical length of the soil core (45 cm),

(see photo #2). A thin top layer of brown silt rested upon a middle black mud/detritus layer (approximately 15 cm) having a slight sulfide odor. The bottom layer of the core was the same grey clay layer supporting both previous sites, except with the addition of detritus. Transient organisms were the sole living macroinvertebrates found. The orders represented were the Amphipoda (Gammaridea) and Ostracoda. A small amount of broken pelecypod and gastropod remains were noted in the sample. Shore birds were noticed to be actively feeding from this station to the most eastern end of Pond 3.

Station 3 Core Composite - No living macroinvertebrates.

Station 4 - Station 4 marked the highest point (at the time of sampling) of direct tidal influence. The sampling site was covered by a 2 cm sheet of very calm water. Because of high and low areas in the western two-thirds of the pond, site 4 may have received a replenishment of fresh water only on high (plus) tides. The high water temperature of the site (19°C) and stillness of the water mat would indicate a low dissolved oxygen level.

The substrate contained a great deal of detritus. A soil core displayed a thin, silty, brown surface mud layer resting upon approximately 25 cm of very black mud high in sulfides. The bottom clay layer was noticed to slope downward from the western end to the eastern end of the pond. As a result the black anaerobic mud layer increased in thickness approaching the eastern end of the pond. Amphipods (Gammaridae) and ostracods were once again the only macroinvertebrate representatives. The number of actively feeding shore birds was highest at this point.

Station 4 Composite Cores - No living macroinvertebrates.

General Synopsis - Pond 3

The history of Pond 3 is an important factor in analyzing the invertebrate community. Prior to a dike breach in December, 1972, the pond had been dry for approximately seven years. During this time the only moisture received was due to annual rains. Therefore, the pond has only been open to tidal action and invertebrate colonization for a period of nine months before analyses. (Oral Communication - Mr. Paul Knudsen, ACE).

In the light of these facts the low numbers of benthic individuals and expected species may be understood. Pond 3 represents only the upper portion of the intertidal zone. The slow movement of tidal waters into and out of the pond with a lack of any surge or currents would not physically encourage the advance of meroplankton into the upper regions of the pond. The thin, shifting topsoil layers and anaerobic detritus-packed lower soil layers of upper Pond 3 may have inhibited pelecypod inhabitation.

Polychaetes were represented in only one area (highest intertidal - Station 1) by a small group of seemingly vacant tube-worm burrows. These burrows were uncovered by Dr. Jerrold Jayne in his investigation of soil types. The complete lack of polychaetes in all of the samples suggests the possibility of a chemical deterent to larval inhabitation. This may be due either to the lack of a necessary chemical(s) or the presence of a harmful chemical(s) in the soil chemical constituents. Particular chemical conditions of the substrate are desired by the pelagic larvae of benthic polychaetes in settling an area.[1] Polychaetes were well represented in a mud flat just 5000 feet south of Pond 3 (control area).

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1. Odom, Eugene P., 1959. Fundamentals of Ecology. W.B. Saunders Company, Philadelphia and London, p. 347.

Eastern pond sites revealed only decomposed or broken pelecypod remains, none of which appeared recent. Natural barriers such as high spots and depressions (mid-pond) seemed to limit the present living bivalve population to the western end of the pond. *Mya arenaria*'s ability to inhabit semi-anaerobic to practically complete anaerobic soils would seem to make it a candidate for the more eastern regions of the pond. However, the clam's inability to survive in silty, shifting soils may explain why it was not found in those regions. The lack of *Macoma inconspicua* in the eastern reaches of Pond 3 is understood considering the high amount of detritus and lack of currents.[2]

Borrow Area

A slight miscalculation in timing left the borrow area altered enough that an acceptable benthic sample was unattainable. The borrow area was scheduled to be sampled approximately ten days after the exploration of Pond 3. Upon sampling, the dredge was found to already have passed disturbing the banks by either clam-shelling the shoreline or depositing dredge spoil on the creek-side of the dike.

Two samples were taken yielding only the gastropod, *Nassarius obsoletus*. The clay substrate of the creek sample sites was so firm the inhabitation by common bay clams is doubtful.

Control Marsh

As was indicated in the section on floristics no one area in the vicinity was adequate to our needs for a control marsh. Both the high-high marsh and the low-low marsh were usually very inadequately represented. However, the low-high and the high-low marsh habitats, such as

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2. Vassallo, Marilyn T., 1972. *The Ecology of Macoma inconspicua in the Central San Francisco Bay*, Part I. The vertical distribution of the *Macoma* community. The Veliger, Vol. II, #3, pp. 223-234.

we expect will prevail at length in Pond 3, were well represented. This was in an excellent salt marsh about 5,000 feet south of the flood control channel. It is basically a high-low marsh on the landward side with an anomalous low-high marsh between it and the bay and exposed at all times except high-high tide.

The control marsh was sampled using a core with a surface area of 0.09 m^2 and a depth of 25 cm (volume 0.022 m^3). The core was especially constructed to cut through heavy above-ground plant growth and below-ground rhizome mats. For convenience of description this marsh is divided into four invertebrate habitats, namely, tidal mud flat, marsh-bay frontage, low-high marsh and tidal canals.

A. Tidal Mud Flat - A "probing" of the mud flat was performed to a depth of 45 cm using a P.V.C. core. The purpose was strictly to find out the firmness of the soils composing the tidal mud and "smelling" for the presence of sulfides. Surprisingly the mud was firm enough to walk on out to approximately 15 meters from shore without the aid of hip boots. To this point the probe produced cores composed of a firm, grey clay over which rested a thin layer of silty mud. Both silt and clay base seemed "healthy" as no sulfide odor was noticed. The softer mud beyond the easily walkable limit began to exhibit a darker color with an increasing odor of sulfide.

The mud directly at the interface between marsh and mud flat was composed of small rocks and fine sand with an overall larger particle size than normal bay muds. Particle size diminished the farther the distance out onto the mud flat from the marsh frontage. Extending approximately 75 meters in both directions along the marsh frontage from the study site (north-south) a great deal of erosion is presently occurring.

The erosion is characterized by very large sections of high marsh frontage (steep vertical face) being undercut and falling as blocks.

After the cutting of a large section of marsh onto the tidal mud flat, wave action wears down those parts not supported by a firm _Spartina_ rhizome structure. Since the section of marsh falls forward, immediate erosion would begin to affect the soil between the extended _Spartina_ rhizome clump and the newly exposed vertical marsh face. The resulting situation is that small rocks combined with heavier soils remain in the area of active erosion while the lighter soil particles are washed out onto the mud flat.

The newly formed vertical marsh face is now exposed for the continuance of this type of erosion. Colonization of the fallen but intact soil masses begins with the attachment of the ribbed mussel, _Modiolus demissus_ on decaying _Spartina_ shoots and rhizomes.

Modiolus individuals align themselves in a vertical position, a position maintained throughout their life cycle. The mussels grow very close together forming a mat of miniature deep gullies and sharp peaks. Waters advancing and retreating over the mat are mechanically slowed, allowing heavier particles to settle out of suspension.

Thus further erosion of the marsh face would be inhibited and the surface level of the soils raised. The result is the formation of finger-like projections out onto the bay mud flat having an angle of 15° to 25° from the horizontal. The marsh building continues as a result of _Modiolus_ promoting particulate matter to settle out and _Spartina_ colonizing and stabilizing the newly settled matter.

B. Marsh/Bay Frontage - A low growing _Spartina_ spatially combined with a rich population of _Modiolus demissus_ are the immediately visible

features of this habitat. The maximum tidal height at which Modiolus was found is thought to be the maximum tidal height. A slight mound or hummock is formed at this height and noticed to extend the length of the local marsh-bay frontage. The rhizome mass was found to house a great number of organisms but a small number of species. Among the Spartina rhizomes were soil pockets containing isopods (cf. Exosphaeroma sp.) or amphipods (Gammaridae) or both. These pockets communicated with the surface through decayed rhizome channels, possibly isopod burroughs. In some cases the amphipods were within the tissues of the deteriorating Spartina stems.

The rhizomes of the Spartina inhabiting the Modiolus-induced hummocks (upper intertidal level) also contained pockets housing large numbers of amphipods with representatives of all stages of the life cycle. One pocket produced two breeding pairs of amphipods indicating that a somewhat ideal but unsuspected habitat for this organism is available. The amphipods are successfully utilizing the water-conducting characteristic of the Spartina rhizome to moisten the exoskeleton. Protection from feeding shore birds is one definite benefit of such a relationship. The Spartina is furnishing conditions for a very specialized niche and a seemingly commensal relationship. Further study into the relationship between Spartina and the Amphipoda, Spartina and the Isopoda, and the intimate contact between isopods and amphipods in the rhizome mass is suggested.

C. Low-High Marsh - This area makes up approximately 95% of the control marsh. Direct water is realized only from plus tides and occasional rains. The rhizomes and roots of the marsh plants located on the marsh could receive water from lower tides via the maze of canals

transversing the marsh while the macroinvertebrate community is directly affected by the lack of water on the low-high marsh.

The only observed macroinvertebrate was Nassarius obsoletus grazing in small isolated ponds formed by previous high tides or rain.

D. Small and Medium Tidal Canals - Three small drainage canals having their western openings directly influenced by Bay tidal action and their eastern openings into the large slough separating the marsh from the mainland were explored for the presence of macroinvertebrates, soil conditions, and tidal exposure. The soils for the most part were composed of loose silt in an anaerobic condition. Erosion from marsh run off and sediment carried by incoming tides most likely account for the high amount of silt.

All three channels exhibited the same topographical and biological characteristics. Sulfides gradually declined as a function of distance from the Bay frontage. Sulfides were not readily detectable in the odor of these canals on the slough-side of the marsh. A heavy growth of Spartina in their basins is the probable cause of the loss of anaerobic conditions.

A heavy mat of Ulva accompanied by amphipods was observed in the bayside one-third of the canal. Enteromorpha was observed mainly in the canals on the slough-side of the marsh. The common snail Nassarius obsoletus was noted in great numbers grazing on diatoms in the bayside canal sections. The numbers of snails decreased as a function of Spartina growth on the canal edges. The higher the Spartina the less sunlight penetration yielding a very sparse diatom growth thereby eliminating the food source for the "grazing" community. Burrowing forms appeared to be absent except at the bayside mouth of the canals. An interesting note

is the ability of small clumps of Modiolus to colonize isolated sections of the most anaerobic canal muds. In some cases the mussels were attached to very unstable holdfasts in seemingly stagnant pools. The adaptability of the ribbed mussel and its role in marsh stabilization is subject to further study. Water flow between the bayside and slough-side of the marsh via the inter-marsh channels is thought to occur only on plus tides.

Sampling Results - (See Table I)

Site #1 - Bay Mud Flat

A random core was taken from the mud flat at a station approximately 10 meters due west of the vertical marsh slope and approximately 100 meters south of the most northern point of the marsh.

The pelecypod, Macoma inconspicua, was the dominant organism. Strong tidal influence combined with the physical characteristics of mud ripples (indicating currents) and a lack of detritus in the surface muds agree with findings by Vassallo[3] who discusses the dominance of Macoma inconspicua in the higher tidal areas.

Signs of clam siphons were not evident during the time of sampling. Pelecypods were represented in the mud sample by the juvenile through adult stages of the life cycle. Nassarius obsoletus was the dominant gastropod in the mud sample.

The low number of crustaceans is understandable. The lack of vegetation and detritus for protection, direct exposure to the elements (the tide was approximately 30 meters offshore from the sampling site), and a large number of shore birds feeding in the area, would leave few unprotected organisms high on the tidal flat. Crustaceans were represented by the order Chelifera, Cumacea, Amphipoda, and most numerous the Ostracoda.

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3. Vassallo, loc. cit.

TABLE I - KINDS AND NUMBERS OF ORGANISMS EXPRESSED IN NUMBER PER METER SQUARE AREA FOR TWO HABITAT TYPES IN THE CONTROL AREA LOCATED 5000 FEET SOUTH OF POND 3*

Organisms	Mudflat Number per m^2	Tidal Gully Number per m^2
Annelida		
Polychaeta		
Phyllodocidae (unidentified)	11	---
Eteone lighti	32	---
Eteone longa californica	64	11
Streblospio benedicti	333	11
Heteromastus filiformis	441	11
Tharyx parvus	86	---
Oligochaeta	11	129
Arthropoda		
Ostracoda	258	32
Malacostraca		
Cumacea	11	---
Chelifera		
Tenais sp.	21	516
Amphipoda	21	11
Mollusca		
Pelecypoda		
Modiolus demissus	---	118
Modiolus senhousei	---	11
Mya arenaria	---	21
Tapes phillipinarium	---	11
Gemma gemma	---	11
Macoma sp.	---	1
Macoma inconspicua	806	11
Gastropoda		
Nassarius obsoletus	43	430
Odostoma sp. (juvenile)	21	---

* The high-low marsh was sampled but only insect larvae were found.

Acknowledgement for Identification:
Molluscs by Allyn Smith; Cheliferans by Milton A. Miller; Polychaetes by William A. Light and Christene Jong.

The Polychaeta were represented in the mud flat by both the largest and the most diverse population as was to be expected in San Francisco Bay benthos.

Site #2 - Tidal Channels

The protection from wave force and weather afforded by the topographic form and silt layer of the tidal gully channels is evident in the number of cheliferans found and in the pelecypod diversity. Mya arenaria and Gemma gemma were found in the silty, partially anaerobic soils. Macoma inconspicua, so prevalent some 15 meters away in the mud flat sample, was absent. This further verifies Ms. Vassallo's theory that Macoma does not occur as a function of high amounts of detritus.

The lack of polychaetes is unexplained. Particle size determinations done on the site showed the majority of particles to be less than 32 microns. Particle size determinations done on pre-fill Pond 3 showed the same particle size. Data are shown in Table V, page 44. The lack of expected polychaetes in both areas may point to particle size as directly affecting the settling of the pelagic larvae. If so, a low number of polychaetes is expected in the Pond 3 planting area.

Site #3 - High-low Marsh

Sample data for the dense Spartina/Salicornia habitat failed to yield significant numbers of organisms.

Chemical and Physical Analysis of Soils

Collection and Handling of Samples

Selection of Sites

In each area to be sampled for mud, three sites were chosen. We tried to select sites so that they represented different types of soils or habitats which made up the area.

Pond 3, before filling with dredge spoil: samples were taken at various distances from the west end. Sites 1, 2, and 3 correspond to stations 1, 2, and 3 in the invertebrate section.

Pond 3, after filling with dredge spoil: The levee was being eroded creating a shallow alluvial fan which spread on top of the dredge spoil in the pond. Samples were taken in relation to this fan.

Borrow area: This corresponds to the same area in the invertebrate section.

Control area: Several distinct habitats were present, three of which were sampled at a plus-tide. Sites 1 and 3 were established marsh areas but differed in distance from and in elevation above the bay, and somewhat in vegetation. Site 2 was on the banks of a shallow channel which did not have much plant growth.

Collection

A device consisting of a polyvinylchloride tube, 5 cm in diameter and about 40 cm long, and a rubber plunger was used to take the core samples.

At each site, three replicates were taken to make up the sample. The replicates were within 15 feet of each other. The three expressed cores for each site were broken into three sections, top 10 cm, middle

10 cm, and bottom 10 cm. The top fractions were placed in a cleaned glass jar, and similarly with the middle and bottom fractions.

At the laboratory the samples were homogenized and then stored at 0-5°C.

Moisture

The water content of each soil sample was determined by the following procedure: a small amount of mud was weighed into a tared container. After drying to a constant weight at 110°C, the container and dried soil were weighed again. Calculations to determine per cent water of the mud were then made.

Table 3 shows that the further inland in Pond 3 from the bay a person samples, the higher the moisture content. This may suggest an increase in the amounts of detritus as one moves inland. The "detritus" fraction results agree with this hypothesis and the total organic carbon contents do not refute it.

One can also see that the percent moisture does not change significantly from the top to the bottom fractions.

Chemical Analysis

Chemical analyses of the soil samples were done by subjecting extracts of the samples to standard, accepted tests.

To prepare a soil extract, a known weight of wet sample, equivalent to approximately six grams dry weight, and 20 ml of solvent were added to a glass container and shaken for a minimum of 15 minutes. More distilled water was added if necessary. The suspension was cleared by centrifugation and the supernatant diluted to 100.0 ml in a volumetric flask. This solution was used in the determinations.

Alkalinity and nitrate determinations used distilled and deionized water as the solvent. Phosphate, iron, zinc, lead, magnesium, and calcium

tests required an acid solvent which was 0.05 N in HCl and 0.025 N in H_2SO_4. The extraction method was provided by Dr. Jerrold Jayne and can be found in Walsh (1970) Instrumental Methods for Analysis of Soils and Plant Tissues, p. 33.

The above values were reported as units per gram dry weight of soil. Mercury and total organic carbon are expressed as units per gram wet weight.

Alkalinity

Alkalinity was determined by titrating with standard acid and a pH meter as described in Standard Methods (1971), p. 52.

Alkalinity is a measure of the capacity of a sample to absorb hydrogen ions, or in other words the capacity to neutralize small amounts of acids. Alkalinity is generally expressed as an equivalent amount of calcium carbonate. In fact, however, not only carbonate ions but also hydroxide, bicarbonate, and other basic ions may be present.

The alkalinity analyses showed no significant differences among the samples, except in the site #1 control area where the values were consistently higher. This may be due to the heavy deposit of the mussel, Modiolus, noted in the site description.

Nitrate

Analysis of the soil extract for nitrogen in the form of nitrate ion was according to the brucine method given in Standard Methods (1971), #213C, p. 461.

The low values seen in the NO_3-nitrogen column support what has been seen by plant reaction to the dredge spoils - very little nitrate is present in the soil. Nitrate is the most readily available form of nitrogen to plants; without it they do not grow well. Reduced nitrogen,

either nitrite or ammonia, and the reduction process are favored in anaerobic conditions. Since most of the nitrogen in this anaerobic system of the mud is most likely ammonia, it is not surprising that the plants will not grow well.

Phosphate

Total phosphate content of the soil samples was determined by subjecting the soil extracts to the ascorbic method described in Standard Methods, #223F, p. 532.

Phosphate is necessary to plant growth. High amounts of available phosphate will increase the root system which leads to a greater uptake of soil phosphate. Soils must be aerated to make the insoluble forms of phosphate available to the plant. Since it appears that the marsh soil is definitely anaerobic the phosphate available to the plant will only be present in small quantities. The method used in this analysis measures the amounts of both soluble and insoluble forms.

Iron

Iron content of the acid extract was measured with an atomic absorption spectrophotometer.

The iron content of the mud samples collected from Pond 3 before filling with fresh dredge spoil and of the sample from the borrow area was determined in Dr. Jerrold Jayne's laboratory. Their procedure was identical to the one which we used, with the exception that they first oven dried and pulverized the mud sample. Apparently this drying step was enough to cause differences between their and our values, as can be seen by comparing the Pond 3 values to the others. Heating at high temperatures causes chemical changes in some metallic complexes and may cause a shift between the ferrous and ferric states of iron (Fe^{+2} and

Fe^{+3}). Exactly what the changes are is unknown, but they seem significant enough to affect the extractability of iron. Hence, the iron values of Pond 3 samples should not be compared directly with the others.

Typical total iron contents of soils are 1-6% Fe_2O_3 (3500-21,000 ppm Fe), but in some areas it may approach the iron content of iron ore.[4]

The reported total iron content of a soil sample can be very misleading when trying to relate it to plant growth. It has been shown that plants require only minute quantities of this essential element, less than 1 ppm.[5,6] However, this must be in a form which can be absorbed by the roots, i.e. soluble in water. How much of the total iron is in this form depends on many factors, such as pH, presence of sulfides, presence of other elements, soil composition, and so on.

Few soils are deficient in iron, but most of it is usually in the form of insoluble oxides, hydroxides, or in anaerobic soils sulfides. This is a problem particularly in alkaline soils, where one also finds the highest incidence of iron chlorosis symptoms on plants. In acid soils containing large quantities of organic matter, true iron deficiency can occur by leaching from the soil. Certain organic compounds, such as fulvic or humic acids, act as chelating agents, bringing the metal into solution. Time and water eventually may remove iron from the upper soil layers.

Zinc

Zinc content of the acid extract was measured with an atomic absorption spectrophotometer.

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4. Bear, Firman, 1964. Chemistry of the Soil, p. 128.
5. Leach and Taper, 1954. Can. J. Bot. 32: 561-70.
6. Glasstone, 1947. Amer. J. Bot. 341: 218-224.

The determinations of samples from Pond 3 before filling were carried out in Dr. Jayne's laboratory. As the case of iron, it seems that the drying of the sample affected the extractability of zinc from the soil.

The amount of dilute acid extractable zinc found in soils from various countries ranges from 0.5-15 ppm; total zinc range from 10-200 ppm.[7] Table 3 shows no unusual deviations from the above values.

Zinc is an essential element, required for plant growth, but it is needed in only very small quantities, less than 1 ppm.[8] Like iron, however, zinc must be in soluble form in order to be available to the plant. Few soils are deficient in zinc, although it may be completely immobilized for the plants.

Lead

Lead content of the acid extract was measured with an atomic absorption spectrophotometer.

As with iron and zinc, the determinations on samples from Pond 3 before filling were performed in Dr. Jayne's laboratory. The drying step appears to have affected the amount of lead going into solution.

One study found lead concentrations in soil to vary mainly from less than 10 to 100 ppm in the south San Francisco Bay, although much higher values were occasionally found.[9] Our values fell within this range.

Magnesium

Magnesium content of the acid extract was measured with an atomic absorption spectrophotometer.

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7. Bear, Firman, 1964. Chemistry of the Soil, p. 365.
8. Stiles, Walter, 1961. Trace Elements in Plants, p. 72.
9. Peterson, D.H., McCulloch, D.S., Conomos, T.J., and Carlson, P.R., 1972. "Distribution of Lead and Copper in Surface Sediments in San Francisco Bay Estuary, California." San Francisco Bay Region Environment and Resources Planning Study, U.S. Dept. Interior, Geological Survey.

Magnesium is an essential element required for plant growth. It is part of the chlorophyll molecule, and many enzymes are activated by the participation of the element.

Calcium

Calcium content of the acid extract was measured with an atomic absorption spectrophotometer.

Calcium, like magnesium, is an essential element for plants. It probably is an important component of pectic substances in the middle lamella, which cements plant cells together.

LFE Environmental was subcontracted to do the analysis of mercury, total organic carbon, and conductivity of the core samples.

Mercury

Mercury levels of soils have been monitored particularly because of the element's toxic effect on animal life and possible concentration in plant tissues.

All values are at or below the amounts reported in other parts of south San Francisco Bay. These other sources[10] indicate 70% of their values fall in the range of 0.13-0.54 ppm Hg on a dry weight basis.

Total Organic Carbon

Total organic carbon is a means of indirectly estimating the amount of organic matter in a sample. Tests were performed on the entire sample of each aliquot (as opposed to an extract).

The values were approximately the same for all sites. They were somewhat but not markedly lower in the Pond 3 dredge spoil. It is

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10. McCulloch, D.S., Conomos, T.J., Peterson, D.H., and Leong, K., 1971. "Distribution of Mercury in Surface Sediments in San Francisco Bay Estuary, California." San Francisco Bay Region Environment and Resources Planning Study, U.S. Dept. Interior, Geological Survey.

estimated that most of this organic carbon in Pond 3 and the dredge spoil is from detritus whereas it is mostly from plant material in the other samples.

In the control area at those sites on which plants are vigorously growing, sites 1 and 3, total organic carbon levels are higher in the upper fractions, probably due to the plant roots. In the drainage channel, which had sparse Spartina growth, the upper layers contained slightly less organic carbon. This may be because of the washing away and/or oxidation of organic debris. Note the lack of sulfide odor in the upper layers, indicative of an aerobic soil.

Conductivity

Conductivity is a measure of the dissolved salts in a sample. Its value depends on the number of ions present, the charge on the ions, and temperature.

The conductivity of the samples from the borrow area was lower than that of the other areas. This indicates a lower salinity, which is expected as one moves away from the bay up the estuary into brackish water.

Particle Size

Particle size determinations were done according to a procedure described by Emery (1938) in the Journal of Sedimentary Petrology 8(3): pp. 105-111.

A weighed mud sample was first sieved through a 0.5 mm mesh sieve to remove large pieces of organic matter, rocks, shells, and shell fragments. This fraction was dried and weighed.

The sieved mud was placed in the "decantation cylinder" described by Emery. This removed the particles less than 32 microns in diameter. The particles left behind, those larger than 32 microns, were dried and weighed.

The percent of particles smaller than 32 microns could then be calculated.

All values were reported on a dry weight basis.

The amount of sand particles greater than 32 microns was too slight for a particle size determination to be performed on them. Reporting this fraction as a percent of dry weight was valid, as there were too few of them to alter the mud structure significantly.

Upon examination of the tables, one will note that by far the major component of all the mud samples consists of "silt" particles, less than 32 microns in diameter. This accounts for its clay-like consistency.

The composition of the large particle fraction should be noted. There appears to be some correlation between the gradation from rocks and shells to well decayed organic matter to undecayed organic matter and an increasing degree of establishment of the marsh.

Explanation of Tables

In certain instances, the top 10 cm, middle 10 cm, and bottom 10 cm of the core samples were homogenized separately and each homogenate analyzed separately. Otherwise the whole core(s) taken at a given site was (were) homogenized together before analysis. This is indicated in the column labeled "fraction".

The symbol "-" indicates the test was not performed on that sample.

TABLE II

SAMPLING SITE AND SOIL DESCRIPTIONS

Area	Site	Location	Description	Fraction	Description
Pond 3 (Before filling)	1	0.3 mi. west end	25 cm layer of loose, black anaerobic mud; high sulfide smell; grey clay lower level; 6 in. water; no plant growth.	composite	sulfide; no roots; grey color
	2	0.7 mi. west end	surface color medium to light brown; shifting sediments; low sulfide; 25 cm layer of plant detritus and brownish-black soil; bottom clay layer.	composite	sulfide; no roots; grey color
	3	1.3 mi. west end	high sulfide; mud to black color with a high amount of detritus; bottom clay layer approx. 35 cm under.	composite	sulfide; no roots; grey color
Pond 3 dredge spoil	1	100 yd. from top	between alluvial fan and fill 30 yd. north of middle of levee; numberous large chunks; no sulfide apparent.	composite	sulfide; few roots; grey color
	2	200 yd. from top	10 yd. into alluvial fan; no sulfide apparent.	composite	sulfide; few roots; grey color
	3		directly from fill; very fluid (slurry); sulfide-strong odor.	composite	sulfide; no roots(?) grey color
Borrow		± 200 m. from Alameda Creek mouth	very solid clay substrate, extremely hard to take core; sulfide odor evident when substrate disturbed; <u>Spartina</u> (tall) growing in basin of study canal.	composite	sulfide; few roots; grey color

TABLE II (CONTINUED)

SAMPLING SITE AND SOIL DESCRIPTIONS

Area	Site	Location	Description	Fraction	Description
Control	1	bay front	steep vertical face toward bay, rhizome mat evident; dense growth *Spartina* (short);	top 10 cm	sulfide; many roots, some rhizomes; grey color.
			heavy mixture of *Modiolus*.	middle	sulfide; fine roots, few rhizomes, grey color.
				bottom	sulfide; fine roots, few rhizomes; grey color.
	2	drainage channel	middle of island, 3 m from slough receiving tidal water; soil stable; sulfide, none	top 10 cm	little sulfide; few roots and rhizomes; brown color.
			in top layers; mixture of dormant *Salicornia*	middle	(same as above)
			and *Spartina*, some new *Spartina* shoots.	bottom	sulfide; few roots, no rhizomes; grey color.
Control	3	"high-low marsh"	near small channel facing bay-south side vertical bank, north side ± 20° slope;	top 10 cm	no sulfide; some roots, no rhizomes; brown-grey color.
			Spartina (tall) invading channel, some new shoots; heavy dormant *Salicornia* samples	middle	some sulfide; some roots, no rhizomes; grey color.
			taken 15-20 m inland; no sulfide odor apparent.	bottom	sulfide; some roots; grey color.

TABLE III

WATER, ALKALINITY, NITROGEN, PHOSPHATE, IRON, ZINC

Area	Site	Fraction	Water % wet wt	Alkalinity mg $CaCO_3$ / g dry wt	µg NO_3-N/ g dry wt.	µg PO_4-P/ g dry wt.	µg Fe/ g dry wt	µg Zn/ g dry wt
Pond 3	1	composite	48	4	< 1	9	--	--
		top 10 cm	--	--	--	--	1400	12.8
		middle	--	--	--	--	1100	3.7
		bottom	--	--	--	--	900	10.7
	2	composite	51	3	< 1	82	--	--
		top 10 cm	--	--	--	--	1200	4.7
		middle	--	--	--	--	1000	5.4
		bottom	--	--	--	--	900	3.7
	3	composite	60	5	2	117	--	--
		top 10 cm	--	--	--	--	1000	3.5
		middle	--	--	--	--	1000	3.5
		bottom	--	--	--	--	900	3.5
Pond 3 dredge spoil	1	composite	48	2	1	27	179	< 1
	2	composite	44	2	< 1	< 1	151	< 1
	3	composite	56	2	< 1	2	164	< 1
Borrow		composite	40	2	6	18	--	--
Control	1	top 10 cm	52	5	< 1	43	50	< 1
		middle	50	8	< 1	64	54	< 1
		bottom	51	8	< 1	71	45	< 1
	2	top 10 cm	49	5	< 1	1	80	< 1
		middle	54	3	< 1	2	139	< 1
		bottom	55	2	< 1	18	124	< 1
	3	top 10 cm	58	2	< 1	20	154	10
		middle	59	4	< 1	55	156	8
		bottom	57	4	< 1	42	144	5

TABLE IV

LEAD, MAGNESIUM, CALCIUM, MERCURY, CARBON

Area	Site	Fraction	µg Pb/ g dry wt.	µg Mg/ g dry wt.	µg Ca/ g dry wt.	µg Hg/ g wet wt.	Total organic carbon % wet weight
Pond 3	1	composite	*	-	-	.085	1.3
	2	composite	*	-	-	.040	1.3
	3	composite	*	-	-	< .028	1.2
Pond 3 dredge soil	1	composite	31	18	82	.035	1.09
	2	composite	29	15	75	.100	0.79
	3	composite	38	16	79	.099	0.58
Borrow		composite	-	-	-	.145	1.6
Control	1	top 10 cm	14	12	49	.140	1.58
		middle	10	11	41	.130	1.01
		bottom	15	12	52	.150	0.93
	2	top 10 cm	20	15	60	.110	0.97
		middle	20	16	70	.120	0.99
		bottom	19	16	66	.094	1.12
	3	top 10 cm	5	17	62	.089	1.16
		middle	20	16	94	.079	1.02
		bottom	21	14	64	.070	0.94

* No positive results. No organic solvent extract used.

TABLE V

CONDUCTIVITY, PARTICLE SIZE

Area	Site	Fraction	Conductivity µmhos/cm²	Detritus and large particles % dry wt. *	Particles < 500µ, > 32 µ, % dry wt.	Particles < 32µ % dry wt.
Pond 3	1	composite	21,420	7	17	76
	2	composite	35,380	4	4	93
	3	composite	35,380	3	32	65
Pond 3 dredge spoil	1	composite	35,400	5	18	76
	2	composite	26,500	7	15	78
	3	composite	46,100	5	16	79
Borrow		composite	14,640	5	3	92
Control	1	top 10 cm	26,500	16	14	70
		middle	32,200	7	16	76
		bottom	28,700	2	10	88
	2	top 10 cm	32,200	2	20	79
		middle	35,400	3	11	88
		bottom	33,200	4	13	84
	3	top 10 cm	27,900	4	4	93
		middle	33,200	9	2	89
		bottom	32,200	7	2	90

* The major component of this fraction varied.
Control-all sites: undecayed plant material, roots, rhizomes
Pond 3-site 2, 3; Borrow: fairly decayed material, mostly fine texture
Pond 3-site 1; Pond 3 dredge spoil: rocks, large sand grains, shells and fragments, very little detritus, no roots or rhizomes

Percentages may not add to 100 due to rounding off.

Microflora

Indicative of the physical nature of the dredge spoil habitat are the biological results obtained in an examination of the microflora and their behavior in a Winogradsky column (Pl.I,1).

The use of a Winogradsky column in this study can be classed as a side experiment to help in achieving a better understanding of the dredge spoils and the microflora present in it. It is a simple way to study, in the laboratory, a cross section of a soils environment such as we hope will establish itself shortly after the dredge spoil is in place in Pond 3.

The column was set up (Aaronson, 1970) in a glass cylinder. Paper towels and calcium sulfate ($CaSO_4$) are placed in the bottom as a nutrient source, on top of which dredge spoil was placed to fill the column to a height of 12 inches. The top of the column is exposed to air; the further down in the column, the less oxygen available until an intensely anaerobic region is reached at the bottom.

Microscopic examination of the column occurred 7 weeks after it was set up. The surface of the mud contained many individuals of a rotifer - *Philodina*, an ostracod in the suborder Cladocopa, and three species of diatoms. The area of highest light intensity (circular area near the surface of the mud and extending downwards approximately 2.5 cm) contained blue-green algae - *Spirulina* and *Oscillatoria*, diatoms - *Gyrosigma* and two species of *Navicula*. No other plankton organisms were found in the water above the mud.

The microaerobic zone, found just below the location of the blue-green algae is a rust color. This zone indicates the presence of iron bacteria oxidizing iron compounds present in the mud.

Further down, in the anaerobic area, red and pink zones are found. These are anaerobic sulfur photosynthetic bacteria. In the presence of light, these bacteria can grow by obtaining oxygen from sulfate ions thereby reducing the sulfate to sulfide.

At the bottom of the column microbial degradation of the paper is occurring. The mud at the bottom of the column is black, presumably with reduced iron sulfides. This indicates the presence of sulfides reduced from calcium sulfate and also indicates the reduction of iron compounds present in the mud. The bacteria responsible are also anaerobic sulfur photosynthetic bacteria.

The algal layers appeared 4 to 5 weeks after setting up the column. By the seventh week the brown and black regions appeared, evidence of iron bacteria and certain sulfur photosynthetic bacteria, respectively. Some pink sulfur photosynthetic bacteria were perceptible. Not until the tenth week did the red sulfur photosynthetic bacteria become visible.

Past experience with columns made up of mud and water have shown that the organisms present usually flourish within 2 to 3 weeks. The column in this study required 5 weeks for any indication of organism growth. At 7 weeks of growth, the column still did not exhibit the vigorous organism growth seen in past Winogradsky columns from different saline and freshwater habitats, although by the tenth week all the general types of organisms were to be found.

From the results obtained so far, a number of interesting facts have been learned about the dredge spoil. The organisms present are what can be expected in this type of environment. The fact that some kinds of organisms required such a long time to appear suggests a difficult environment that the dredge spoil presents. The most apparent

reason for this slow growth may be the very small particle size of the spoils. The small particle size would impair diffusion of nutrients throughout the column, thus slowing down the growth of all organisms present including those not yet seen but possibly present in the column.

If this microbe growth behavior is indicative of the harsh nature of this dredge spoil as a biological substrate, then it would not be surprising to find that plants may have a difficult time establishing themselves in the dredge spoil. Oxygen diffusion would be retarded markedly by the small particle size. Slow nutrient diffusion through the mud could result rapidly in nutrient deficiencies localized immediately around the plants. This last property may be useful, however, if it helps to hold chemical fertilizers placed deliberately on the planting sites.

III. Artificial Propagation of Spartina and Salicornia

The propagation of cuttings was largely planned and put into operation by Mr. John Jackson, M.A. In making the cuttings our preliminary experience had seemed to indicate that we would have no problem with *Salicornia* but that we knew nothing about the horticultural behavior of *Spartina foliosa*. Hence our first attention was directed toward *Spartina* (Pl.I,2). As indicated below several types of cuttings were attempted including culms, tillars, crowns and rhizomes. We found crowns most practical in the long run. These had 1, 2 or 3 tillars each and were recorded as having single or multiple tillars. A few culms were added in the hope that they might give rise to sprouts at the nodes. These failed to grow. Cuttings of the very succulent rhizomes, although still appearing healthy, have as yet produced but a very limited evidence of growth. Separate records were kept for the different cutting types, although except

for the failure of the culms and the inactivity of the rhizomes, no significant differences relatable to the kind of cutting were observed. What differences we have observed are relatable either to soil medium or to the rooting hormone used.

Propagation facilities currently consist of twenty-five wood tanks four feet by eight feet and eleven inches deep.(Pl.II,1,2), lined with 10 mil. black plastic sheeting to contain the water. Salt water was provided from San Pablo Bay by a salt water plumbing system. The water enters each tank from the top at one end and exits about two inches above the bottom so that there was always two inches of water in each tank. However the outlet was so organized that it was possible to control the water level up to total capacity. The system also allowed each tank to be operated independently of every other tank, that is, filled and drained independently. Two tanks were equipped with soil heating cables that automatically shut off at 23°C. One tank was covered with translucent 10 ml. plastic sheeting to try out its "greenhouse effect".

Sand was placed in the bottom of each tank up to the level of the bottom of the drain pipe. Pressed peatmoss pots filled with different types of soil media were placed on the sand. The object of the sand was to receive any roots that might penetrate the pots. Two sizes of pots were employed,namely 2" and 3".

Growth Media and Hormones

Rooting media, herein sometimes called "growth media", for <u>Spartina</u> consisted of five kinds, namely 1) river sand from Felton, 2) a mix of ½ dredge spoil and ½ sand, 3) a mix of 1/3 vermiculite and 2/3 sand, 4) vermiculite with a layer of sand on top, and 5) a mix of ½ dredge spoil and ½ vermiculite.

Cuttings were either treated with a commercial rooting hormone or left untreated for the control. Treatment was prior to placing the cuttings in soil in the pots. The commercial rooting hormone "Rootone", a powder, consisted of the following ingredients: 0.067% 1-Naphthaleneacetamine, 0.033% 2-methyl-1-naphthaleneacetic acid, 0.13% 2-methyl-1-naphthaleneacetamide and 0.57% Indole-3-butyric acid. The rooting hormone "Hormodin #2" is a powder consisting of 0.3% Indole-3-butyric acid. The rooting hormone "Jiffy Grow" is a concentrated liquid with 0.5% indole butyric acid and 0.5% 2-naphthalene acetic acid in it. The Jiffy Grow was diluted 1 part concentrate to 10 parts water.

Different combinations of growth medium and hormone employed were as follows:

Sand only: with no hormone (control), Hormodin, Jiffy Grow, Rootone and heat, Rootone and fresh water.

2/3 sand and 1/3 vermiculite: control, Rootone.

Vermiculite with sand top: Hormodin.

½ dredge spoil and ½ vermiculite: Hormodin, Rootone.

½ dredge spoil and ½ sand: control, Hormodin, Jiffy Grow.

The following summary of the work on the *Spartina* cuttings and the results obtained was edited from a report by Meigs Matheson who worked very closely with Mr. Jackson and myself in the day to day assessments of the *Spartina* problems.

"The *Spartina* cuttings were grown under 15 different conditions, namely three rooting hormones and a control, in 5 different growth media. In addition two small scale experiments were attempted to root *Spartina* in fresh water and sand.

"Examination of results for the final report entailed a random selection of three plants from each situation, gently washing away the

soil, their condition recorded and photographed. It seemed clear that roots and tops were under different growth regimes. Whereas 75% of the plants examined did show root growth and 70% of the plants showed some shoot growth either elongation or the addition of buds, when these figures were broken down in terms of the different soil media and the different hormones employed, 25% showed good root growth and no shoot growth and 12% exhibited new shoot growth with no root growth. Best results as to root growth were attained with the heated sand and Rootone combination, and with the sand-mud mixture; however shoot growth was poor in both cases. Most favorable response was attained with "Jiffy Grow" for shoot growth. However almost every treatment including the controls produced a few individuals with outstanding growth. Each treatment also shared the percentage of failures. Shoots grown in mixtures containing dredge spoil seemed to go into winter dormancy faster and more completely than the rest.

"The controls however did very well, so much so that even though we can show that hormones gave good results we think that they were not enough better than the controls to justify the work and expense involved. Whereas the addition of heat gave some exceptional examples of faster and more vigorous root growth, the overall result was not sufficiently different to justify the expense. Perhaps it would be more meaningful to put our statement in the perspective of the controls and say that the controls were such as to justify the use of sand or sand and vermiculite as soil media without the addition of rooting hormones. The fresh water experiment gave us no better results than did salt water. There was evidence that the plants in fresh water were a bit slower in reaching winter dormancy. Complete winter dormancy was assessed as the condition

TABLE VI

SPARTINA FOLIOSA DATA

Growth Medium		Control			Hormodin			Jiffy Grow			Rootone			Rootone and Heat			Rootone and Fresh H_2O Inside			Rootone and Fresh H_2O Outside		
		#1	#2	#3	#1	#2	#3	#1	#2	#3	#1	#2	#3	#1	#2	#3	#1	#2	#3	#1	#2	#3
Sand	Shoots	0	1	2	2	2	0	1	2	1	1	1	3	0	2	2	2	1	1	2	0	0
	Roots	1	0	2	0	3	4	0	4	0	3	2	2	4	4	2	1	2	3	3	4	0
2/3 sand	Shoots	3	2	2							0	1	2									
1/3 vermiculite	Roots	0	4	3							0	3	3									
Vermiculite	Shoots				1	2	2															
with sand top	Roots				3	3	1															
½ mud	Shoots				0	0	1				1	1	1									
½ vermiculite	Roots				3	3	1				3	3	1									
½ sand	Shoots	2	2	0	2	0	0	2	2	2	2	0	0									
½ mud	Roots	3	4	3	4	3	3	3	2	3	3	4	3									

Numbered columns are plant numbers

Shoots were assigned numbers according to the following plan:

0 = no tillars and no shoots
1 = tillar elongation
2 = new shoots or new tillars
3 = many or strong new shoots or tillars

Roots were assigned numbers as follows:

0 = no new roots - old roots not functional
1 = old roots still functional
2 = new secondary roots
3 = new roots or rhizome buds
4 = many or strong new roots

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when last year's culm lost all active chlorophyll and appeared dead. Chlorophyll was retained in lateral tillars which showed little or no growth through the winter. Other evidence of life during dormancy was the formation of healthy shoot buds below ground."

<u>Salicornia</u> Cuttings

In July, prior to the activation of our project, one of our staff conducted a preliminary small scale experiment on the rooting of *Salicornia* in sea water. Results were 100% favorable within two weeks time without any evident shock. This led us to suppose that we would have no trouble rooting *Salicornia*. As a consequence we left the *Salicornia* work until all of the *Spartina* cuttings were in. This was about the middle of October.

Much to our chagrin the entire planting was promptly reduced by shock to a semi-wilted mass from which only a very small percentage seemed to recover. The remainder turned brown and appeared as if dead. About the end of November a visit to a natural salt marsh in a winter condition of dormancy displayed a natural stand of *Salicornia* that visually did not appear much better than those in our cutting tanks.

However, by the middle of December our cuttings began to show evidences of life and to be breaking dormancy. Many plants thought to have died began to show anywhere from 2 to many green buds. The net result is that we expect to have as many successful *Salicornia* percentage-wise as we will *Spartina* cuttings. We suspect that the usual period of shock attendant upon the making of cuttings prematurely activated the onset of winter dormancy in our cuttings of *Salicornia*.

For the *Salicornia* study the same type of propagating tanks and the same rooting hormones were used. In addition one tank was provided

with bottom heat as in the _Spartina_ study and one tank was provided with a lath cover of about 50% in the hope of salvaging the content from initial shock. This did prove beneficial, as indicated below.

A cutting consisted of from 4 to 6 inches of the terminal end of an upright branch system. Growth media were the same as for the _Spartina_ study except that because of the very succulent nature of the _Salicornia_ no dredge spoil mud and sand mix was used.

As indicated above the _Salicornia_ cuttings, with very few exceptions, went into early dormancy and for nearly two months seemed to progressively degenerate from apparent shock. Most were presumed to be dead. Two observations were made simultaneously about the middle of December. Tiny green buds were beginning to appear among the branches of the brown stems, and what we thought were decaying inflorescences became covered with seedlings. The soil of the propagating tanks now contain several hundreds of seedlings.

A random selection of plants to examine for this report indicated that virtually every plant selected exhibited some new shoot growth. As with _Spartina_ "Jiffy Grow" elicited the best shoot growth in all of the soil media employed. The soil media with respect to shoot growth was equally effective except for the mixture of dredge spoil and vermiculite. Here the results were dramatically poor for both shoot growth and root growth.

With respect to root development, as in _Spartina_, root development was not necessarily correlated with shoot growth. Roots occurred on many cuttings whether or not they exhibited shoot growth and vice-versa. However in contrast with the shoots only 35% of the plants examined had as yet developed roots. In the heated tank the percentage and vigor of

TABLE VII

SALICORNIA DATA

Growth Medium		Control #1	Control #2	Control #3	Hormodin #1	Hormodin #2	Hormodin #3	Jiffy Grow #1	Jiffy Grow #2	Jiffy Grow #3	Rootone #1	Rootone #2	Rootone #3
Sand	Shoots	1	1	1	2	0	3	3	2	3	2	1	1
	Roots	0	+	0	0	+	+	+	0	0	+	0	0
Sand with heat	Shoots				1	2	2	3	3	2	1	2	1
	Roots				+	+	+	0	0	+	0	+	+
2/3 sand 1/3 vermiculite	Shoots				1	2	2	1	3	2	1	1	2
	Roots				0	+	0	0	0	+	0	0	0
2/3 sand 1/3 vermiculite with ½ shade	Shoots				2	1	2	3	3	3	3	2	2
	Roots				0	+	0	0	+	0	0	+	+
½ mud ½ vermiculite	Shoots				1	1	1	1	1	1	1	1	1
	Roots				0	0	0	0	0	0	0	0	0

Shoots were assigned values as to the presence of new buds and growth as follows:

0 none
1 *one or little*
2 good but not vigorous
3 abundant and vigorous

"#" indicates sample number.

In the case of roots only presence or absence is indicated. However, we must bear in mind that whereas in <u>Spartina</u> the type of cutting was such that three regions of the plant could produce roots namely, old roots, crown tissue and the bases of tillars, in <u>Salicornia</u> cuttings only old stem tissue was available.

the roots were somewhat greater especially where Hormodin was employed as the rooting stimulant. In the mud and vermiculite mix no roots were found. The best all around soil medium was plain sand (Pl.I,2).

The shaded tank, as indicated above, did slow down the deterioration of the cuttings. Many of the tops here recovered their turgor and remained green even though they did not grow. Indeed very few were given up prematurely as dead. They too have now resumed growth. Thus the addition of vermiculite to sand, the addition of heat, the addition of shade all seemed to yield better results. Indeed of all of our cuttings work where sand was employed with hormones the Salicornia experiment is the only case where the control displayed mediocre results. In the Spartina experiments, although the control showed slightly lower results they cannot be said to be mediocre. It must be born in mind in this connection that our experiments were performed at a time when the plants were about to go into dormancy and the first steps might already have been taken.

Germination Studies

Spartina

The seed studies, by the very nature of the biological calendar in California, were destined to non-completion before the project was activated. With seed ripening in late September and early October and a period of two months after-ripening required, only a limited number of experiments could be undertaken on seed still under the influence of natural germination inhibitors. We have learned that any project concerned with the planting of Spartina seed must acquire its seed the fall before the project is activated if it is anticipated that the project be completed before the next harvest is possible. However we were able

to pursue several investigations aimed at breaking down the inhibitors and have some interesting results.

Seeds were planted in several limited tests of 100 seed each seeking a response to different treatments detailed below, and some large scale tests out of doors were undertaken. In the latter, while the seed remain plump and healty they still seem unable to cope with the climate of our wet winters. We expect that in due course they will germinate and produce an abundance of seedlings when the normal germinating conditions for Spartina seed are reached. Indeed this past week (December 27th) some of our cultures have begun to display an increase in activity.

In the meantime we had learned from the literature and from oral communications with other investigators more experienced with Spartina seed germinations that 1) the seed requires soaking in fresh water prior to germination; 2) it must be stored in salt water to retain its viability at cold but not freezing temperatures and not allowed to dry; 3) a period of after-ripening of about two months is required before germination, presumably to bring about a breakdown or leaching of inhibitors to germination; 4) after-ripening can be speeded by soaking the seed for two weeks in fresh water.

These facts had not yet been demonstrated for Spartina foliosa, our western material. We have now observed that the first three points hold for the western material but the fourth gave very varied results in its effect upon S. foliosa. Some seed responded for a part of it while the remainder displayed the usual delayed but continuing germination with time described below. This indicated that two weeks was not enough to breakdown or leach the inhibitors in all of the seed. It may be that our temperatures were too low. We stored our seed in unheated rooms in November where temperatures ranged from 48° to 52°F.

Harvesting and Threshing Seed

In our search for a source of seed we immediately ran into problems. All of the early sites that we examined provided no seed and no evidence that the plants had produced seed. This evidence consisted of all the inflorescences observed having their chaff intact and not shattered as would be the case if the seed had fallen. Most grass inflorescences shatter when they naturally shed their seed. It was not until mid-October that we found an adequate source of seed. This crop was just maturing to ripeness and had not yet begun to shatter. The location was along the mouth of Petaluma slough in the low-low marsh close to the high-low marsh. No Salicornia was present where the seed was taken.

Harvesting was a three-man operation. One manned the boat, another bent culms over the boat with a pole while the third clipped the inflorescence into the boat with a hedge shears. The inflorescences were then sacked in plastic garbage can liners holding about 1½ bushel of inflorescences when settled. This operation proved to be surprisingly efficient for in six hours of actual collecting by three men yielded approximately several hundred thousand seed stored in nine one-gallon jars at a temperature of 39°F.

Threshing the seed was another problem. Fair results were obtained by placing the inflorescences in a box with a screen bottom and playing water from a hose on them under some pressure. We took what came easily the first time and held the residue for a later trial. It required three such operations before the inflorescences were completely shattered. The last operation yielded chaff with much fewer seed than did the first two operations.

Another method was to soak the inflorescences in cold salt water for two weeks. These shattered easily and completely from water pressure from the hose. Seed and attached chaff were then placed in gallon jars and filled with salt water then stored in a refrigerator.

Germination Time for Spartina Seed

When the normal date for seed germination for Spartina in nature is is difficult to assess. It is known that Spartina requires soaking in fresh water before it germinates and this is in accord with our findings for S. foliosa. However, S. foliosa, like many other California plants, has a very spotty and protracted sequence of seed germination sometimes lasting very long times. Seeds planted ten weeks ago continue to germinate a few a week. Some tests in this time have germinated 60% of their seed. As yet we have had no tests that displayed a rapid germination of a large percentage of the seed. We have had cases where as much as 10 or 11% germinated quickly and then germination continued a few at a time.

It was observed that in nature inflorescences soaked by heavy rain or fog, where water hung in the inflorescence sometimes for several days, had several seed that were bright green. Examination disclosed that the chlorophyll in the embryos of the seed had become activated while still in the inflorescence. In our germination studies we have found that seeds go through this activation of the chlorophyll just prior to germination and germination follows in anywhere from a few days to two weeks by an elongation of the raducle from which the root emerges. It is the first visible step in the germination operation of our Spartina seed in the laboratory. In other cases the shoot turns upward first followed by the elongation of the radicle. This activation of the chlorophyll in the embryo of seed while still in the inflorescence of the parent plant

we infer is the first step toward natural germination. These seeds with germination well under way drop into the salt water where we postulate germination continues. We found these green seeds are easily removed from the inflorescence. The others hang on tenaceously. It seems likely that we get a continuity of seedling production throughout the early part of the rainy season. However frequent dense fog such as we have in this region can condense enough water in the inflorescence to saturate them.

At length the spent culms rot off dropping the inflorescences and any remaining seed into the water. What happens to these seed and how long they can remain viable is at present unknown. Our experience has indicated that soaking the seed in cold salt water at length induces the seed enclosed in the glumes to drop off.

Germination Experiments on Spartina

The experiments each involved 100 seeds or a number in which the calculation of percentages was easy. We attempted to germinate seed both in fresh and salt water and both in light and in dark. By light we mean the natural alternation of day and night. However several were kept in continuous artifical light. Treatments of the seed involved the same hormones that we applied to the cuttings as well as activated charcoal and other chemicals which we hoped would bind anything which could be a biochemical inhibitor to germination. Table VIII is a resume of the experiments on Spartina.

As would appear from the figures germination has been very spotty and protracted. Some of this slowness is to be charged to the seasonal conditions that prevail at the time of the study. More is to be charged to the fact that the seed being tested were in a state of after-ripening which the methods we employed did no more than "nibble" at. At the time

TABLE VIII

SPARTINA FOLIOSA GERMINATION DATA

Treatment	Date Planted	Number of Seeds	Time Lapsed in Weeks 1	2	4	10	Total % Germinated
Petri dishes:							
Fresh water	10/18	61	11		21	10	42
Fresh water	10/23	100	15		15	8	38
Fresh water - dark	10/23	100	5		6	7	18
Fresh water, charcoal	11/30	100	10		4		14
Saltwater, charcoal	11/30	100	6		5		11
Fresh water	11/30	100			10		10
Salt water	11/30	100			2		2
Fresh water, Jiffy Grow	11/30	50			14		28
Salt water, Jiffy Grow	11/30	50			3		6
Fresh water, Rootone	11/30	50			4		8
Salt water, Rootone	11/30	50			3		6
Distilled fresh water	12/18	100		2			2
Salt water	12/18	100		2			2
Fresh water, charcoal	12/18	100		0			0
Agar	12/18	100		4			4
Cellulose gel	12/18	100		0			0
Alumina	12/18	100		2			2
Buffer, pH 4	12/18	100		2			2
Buffer, pH 7	12/18	100		3			3
Buffer, pH 10	12/18	100		1			1
Sand in Jiffy pots:							
Fresh water outside	11/20	1,000			30		3
Charcoal, Fresh water outside	12/12	350		14			5
Fresh water inside	11/19	1,000			48		5
Fresh water inside	10/30	380			20	28	13

NOTE: Data on seedling survival in Appendix B.

of this writing which is the time of close of the period of after-ripening of our seed all of the cultures both indoor and outdoor, both in fresh water and salt water and regardless of how long the culture has been maintained, display evidence that something is about to happen. That is to say that in the last few days many of the seeds are getting green and some have already begun to elongate their tops. We postulate that this is the prelude to the end of after-ripening and our seed supply is finally ready to work on.

Of the above trials the most dramatic was that in which activated charcoal was employed. This gave 10% germination between 2 P.M. one day and 9 A.M. the next, followed by the usual slow down to a trifling amount. We suspect that what happened here is that 10 percent of the seed was about ready to germinate and the charcoal speeded them on their way but was not sufficient to take care of the remaining seed.

From what we have learned the likeness of response of our plants to that of plants employed by the eastern researchers leads us to believe that there is no reason to suppose that results obtained on the east coast cannot be obtained here with our material. Only now is our seed in a condition for effective germination tests. These should be continued and seedlings be made available for the Phase II study.

Experiments with Salicornia Seed

Salicornia seed was gathered from three different races of plants growing in the vicinity of the Alameda Flood Control Project. One was from the high-low marsh and of a type that was uniform throughout the marsh. Another was from the high-high marsh and the third from close to the border of high-high and low-high marshes. The latter two represent extremes in what are seemingly a part of a genetic complex that inhabits the high marsh. One is erect, the other is spreading to prostrate.

TABLE IX

SALICORNIA GERMINATION DATA

Treatment	Date Planted	Number of Seeds	Time Lapsed in Weeks				Total % Germinated
			1	2	4	10	
Petri dishes:							
Fresh water	10/23	100	3		20	38	61
Fresh water, dark	10/23	100	4		10		14
Fresh water	10/23	86				13	15
Salt water, oven dried	10/29	150				50	33
Salt water, room dried	10/29	100				64	64
Tall variety:							
Salt water	11/30	50			2		4
Fresh water	11/30	50			0		0
Salt water, Jiffy Grow	11/30	50			0		0
Fresh water, Jiffy Grow	11/30	50			0		0
Salt water, Rootone	11/30	50			2		4
Fresh water, Rootone	11/30	50			0		0
Salt water, charcoal	11/30	50			3		6
Fresh water, charcoal	11/30	50			0		0
Spreading variety:							
Salt water	11/30	50			0		0
Fresh water	11/30	50			0		0
Salt water, Jiffy Grow	11/30	50			0		0
Fresh water, Jiffy Grow	11/30	50			0		0
Salt water, Rootone	11/30	50			0		0
Fresh water, Rootone	11/30	50			0		0
Salt water, charcoal	11/30	50			0		0
Fresh water, charcoal	11/30	50			0		0
Dominant variety:							
Salt water	11/30	50			1		2
Fresh water	11/30	50			2		4
Salt water, Jiffy Grow	11/30	50			0		0
Fresh water, Jiffy Grow	11/30	50			0		0
Salt water, Rootone	11/30	50			1		2
Fresh water, Rootone	11/30	50			0		0
Salt water, charcoal	11/30	50			0		0
Fresh water, charcoal	11/30	50			0		0
Sand in Jiffy pots:							
Tall variety, salt water	10/30	100				4	4
Dominant variety, salt water	10/30	200				52	26
Spreading variety, salt water	10/30	200				140	70

Inflorescences were brought in and dried. Some were air dried and others dried in an oven at 80°C. In addition inflorescences on the *Salicornia* cuttings were left on. These had ripe seed and were allowed to rot in the tanks distributing their seed over the soil of the pots.

Germination time for seed tried in fresh water straggled along with a few in a week increasing up to a month. Germination in salt water was much slower to begin but much more abundant when it did begin. At two months 55% were germinated. Success of the inflorescences left out of doors in the cutting tanks suggest this is the practical way to produce *Salicornia* seedlings. They are now germinating in abundance suggesting that this is their natural time for germination. One point is clear, however. Early morning sun is very important to the germination of *Salicornia* seed. Only in tanks receiving early morning sun is there any germination and only on the side of the tanks that the early sun reaches is there any germination. These seeds were a bonus to our efforts. We estimate between 500 and a thousand seedlings will be available.

IV. Phase II of the Marsh Construction Study

It is one thing to gain a knowledge of the methods of artificial propagation of salt marsh plants and quite another to learn to establish such propagules in a viable condition in a habitat such as that presented by unstable dredge spoil. Our first confrontation with this habitat was when we placed a set of *Spartina* cuttings in unaerated dredge spoil and all of them promptly rotted off just below the soil line forcing us to abandon this experiment. We believe this rotting was due to anaerobic organisms. In any event the soil in the pots gave forth a very strong hydrogen sulfide odor.

A review of the physics and chemistry of the dredge spoil leaves much to be desired as a growth medium for marsh plants. The density of the soil militates against rapid diffusion so that natural correction of the situation will take a very long time. As a consequence, if this state of affairs is to be speeded up, even for Phase II of the study, there is room for much serious thought as to what can be done about it. It should also be pointed out that the soil is very deficient in both phosphorous and nitrogen in a form available to plants. The study of this soil by means of the Winogradsky column indicated the very slow response of organisms to it.

I think that we are well on our way toward understanding and knowing what to do about the plant propagation problems both by way of cuttings and seed. However, it has become clear that this is only the first step in the problem. The next step is finding a way of correcting or of circumventing the soils problem. I use the word "circumventing" advisedly because of implications generated out of our knowledge of the physiological anatomy and physiological ecology of Spartina.

Spartina is often referred to in the biological literature as a plant of anaerobic soils. Although this is in part true there is evidence that it is not wholly true. The circumstances under which we find Spartina suggests that something is happening in the physiology of Spartina foliosa that tends to correct this situation in the soils in the immediate vicinity of its roots.

The evidence from the soils follows. Wherever we find Spartina growing naturally the soils around the roots and rhizomes of the plants do not have the characteristic rotten egg smell of sulfides common to anaerobic soils of salt marshes. However one does not have to dig very

far to find it. This suggests that aerobic conditions prevail immediately surrounding the underground system of the plant. This conclusion is further attested by the finding of the color of iron oxide near Spartina roots indicating a source of oxygen in the soil that enabled bacteria to oxidize the iron.

Certain inferences can be drawn from our knowledge of the physiology and anatomy of Spartina as well as that of certain other halophytes. When we investigate the rhizomes of Spartina we find that they are very succulent because of an air conducting tissue known as aerenchyma which communicates through other plant tissues with the stomata of leaves and culms. Oxygenation of the underground system of the plant is through this air communication system. These tissues have been studied for S. townsendii by Southerland and Eastwood.[11] Preliminary examinations of S. foliosa by Professor Kasapligil of Mills College indicates a close anatomical similarity of S. foliosa and S. townsendii (oral communication).

A second inference can be drawn from our knowledge of Salicornia and the salt content of its tissues. Work has been done which suggest that older ideas indicating that water relations of roots was strictly from the outside to the interior no longer hold. It has been shown (Waisel, 1972) that Salicornia both takes up salt in solution and gives off salt in solution from the roots so that the salt content of any particular plant is high in the early morning and late afternoon and otherwise low. This two way water movement has been demonstrated for other plants as well. The inference with respect to Spartina is that oxygen in solution can be given off by its roots and transmitted to the soils either in solution or

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11. G.K. Southerland and A. Eastwood. Physiology and Anatomy of Spartina townsendii, Annual Bot. 30, 1916, 333-351.

by diffusion. This has important and far reaching implications for the success of the marsh construction project.

Recommendations

In the face of all of the problems presented by an unstable dredge spoil and the seasonality interference with the seed tests, it would seem that good judgement dictates that Phase II be divided into an interim phase 1) for holding the plants developed in Phase I and 2) continuing the studies on the seeds, as well as 3) introducing a very small study on testing out the feasibility of certain methods for circumventing the anaerobic features of the dredge spoil habitat that we anticipate using in the pilot study. 4) We are also going to have to design and build equipment for the pilot study. This could be done during the interim phase so that help assigned to this could be on hand as additional help when needed in the seed study continuation and the carrying over of the plants for the pilot study.

Thus the funding required would be a very little more than would be required to carry the plants over the interim and carry on those aspects of the pilot study necessary to put it into operation.

1. Carry-over of plants from phase I	300 man hours
2. Setting up and monitoring seed studies.	500 man hours
3. Setting up and monitoring dredge spoil experiments	300 man hours
4. Design and build planting structure and tools . .	200 man hours
Total	1300 man hours

The difference is a total of 1000 man hours required to take care of the additional work.

Proposed Monitoring Schedule of Pond 3

Monitoring of Pond 3 during Phase II should be concerned with the welfare of the plants including data on the different treatments. This

will involve survival, general well being, height of plant, number of stems, a judgement as to vigor of relative plants in a natural stand, any flowering or setting of seed; benthic data in the vicinity of the plant stands and a control away from the stands; oxygen levels of the soils in the stands against a control in a comparable place away from the plant stands. Data should be taken at 1) the time of planting (May), 2) period of expected peak of biological activity as indicated by the control marsh (late August), and 3) time of seed production (early October).

V. Cost Analysis

For the purpose of considering costs the project was divided into two sets of objectives: 1) the gaining of knowledge on the propagation of salt marsh plants, and 2) the production of plants for use in Phase II. It is the costs of the latter that we take to be the objective of the cost analysis even though they are in a sense a byproduct of the former. Hence, to be charged against the cost of producing the plants are:

Labor and share of supervisors time includes collection and processing seed and planting the cuttings.
All expendable items for the nursery, pots, soils fertilizer, hormones, plastic sheeting, and miscellaneous purchases, power and water.

Item	Estimated Cost (exclusive of overhead)
Supervision	$1,000.00
Labor	3,000.00
Expendable supplies	452.00
Total	$4,452.00

Estimated number of plants now available: 7,275. Estimated cost per plant: 61¢ exclusive of overhead costs. A more exact analysis would reduce this by a few cents but not enough to be significant. However in the gaining experience that we now have we could reduce it a second time around. (Appendix A)

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Adams, D. A., (1965). Factors influencing vascular plant zonation in North Carolina salt marshes, Ecol. 44: 445-456.

Adam's study was initiated to: (1) quantitatively describe the vegetation of North Carolina salt marshes, (2) determine variations in critical environmental factors which effect distribution of salt marsh macrophytes, (3) formulate levels of tolerance for various salt marsh species and (4) discover evidence of past vegetational changes. Four demonstrable species associations were divided into two zones: (1) Low marsh: a - *Spartina alteriflora*, b - *Spartina alterniflora*-*Salicornia perennis*-*Limonium carolinianum*, c - *Juncus roemerianus* and (2) High marsh: d - *Aster tenuifolius*-*Distichlis spicata*-*Fimbristylis castanea*-*Borrichea frutescens*-*Spartina patens*. The primary factors controlling distribution were tide-elevation influences and salinity. The mean elevation of occurence above mean sea level divided by one-half the mean tide range of the area concerned is a direct constant for each of the salt marsh species. Most salt marsh species exhibit reduced growth and fertility with increasing salinity. Greenhouse studies of variable salinity and soluble iron levels were conducted on *Spartina alteriflora*, *Distichlis spicata* and *Juncus roemerianus*. Planting materials were held in plastic trays with a sterile sand substrate. This soil solution was equivalent in electrical conductivity of a 2% NaCl solution (33-50 mmhos/cm). The nutrient solution used was full strength Hoagland's solution #1. All samples of *Spartina alteriflora* became chlorotic with soluble iron levels of less than 10 ppm. The other species were unaffected. Also, field observations on well-drained areas of *Spartina alterniflora* indicate a tendency for chlorosis. *S. alterniflora* tolerates salinities of 0.5-4.0% salinity but lab samples grow most rapidly in fresh water.

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Distichlis spicata, a salt marsh grass, sets dormant seeds which exhibit a low-temperature, after-ripening requirement. Amen et al studied this phenomena by the following methodology: Seeds were determined to be viable by exposing samples to triphenyl tetrazolium chloride after 24 hours of imbibition. Seeds were then artificially stratified by layering samples on moist filter paper and storing them for four weeks in darkness at 4°C. Stratification, local scarification (rupture of pericarp and testa with a scapel) and nitrate ($NaNO_3$) were all found to be effective agents in breaking dormancy and promoting seed germination. The pericarp and/or testa are impermeable to organic plant growth regulators but not to water or inorganic salts. Gibberellic acid and kinetin are ineffective in breaking dormancy and do not effect germination. Abscisic acid, however, effectively inhibits stratified and scarified seeds. Dormancy and germination appear to be hormonally controlled. It is suggested that the endogenous inhibitor constitutes a block to nitrate reductase activity (i.e. NADPH FAD Mo NO_3) in the endosperm. Presumably, the inhibitor blocks specific DNA transcription sites in the aleurone cells, but can be overcome by after-ripening (inhibitor decay), abrasion (inhibitor leaching) or nitrate induction. Also, there is a 14 day periodicity in the germination responses which even occurs in controls

which have not been stratified. This periodicity may coincide with tidal flux. Maximal germination, in terms of percent of seeds responding, occurred in samples which were exposed to a low-temperature thermoperiod (i.e. 4-27°C, 10 hour photoperiod). The seeds were not photosensitized to red or far-red light.

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The germination and growth response of Cakile maritima Scop. to temperature, light, and soil- or air-borne salinity was investigated in the laboratory and the results compared to field observations at Bodega, California. The silicle contains two dimorphic seeds, but there was no evidence that their germination requirements differed. In some respects, Cakile seems adapted to the saline, open strand environment: germination and root growth were not inhibited by 0.1 and 1.0% NaCl; overall seeding growth was not inhibited by 0.8% salt (diluted sea water); amounts of salt spray which inhibited growth of a grassland species had no effect on Cakile; germination was inhibited by light (seeds germinate 5-10 cm below the surface on the strand); and shoot growth was greatly stimulated by light intensities above 1500 ft-c. In other respects, Cakile seems better adapted to the adjacent grassland environment: transplant tests indicated optimal growth of seedlings in weeded grassland soil rather than in strand soil. Its normal exclusion from the grassland was hypothesized to result from shading by more vigorous grassland species.

Cameron, Guy N. (1972). Analysis of insect trophic diversity in two salt marsh communities, Ecol. 53(1): 58-73.
This study analyzes trophic relationships of the insect component of two intertidal salt marsh communities dominated by Salicornia pacifica and Spartina foliosa, respectively. Seasonality of that component is determined and influence of physical microenvironmental factors on trophic diversity is assessed. Adult insect populations were monitored weekly, tropic diversity was computed, and realtionships with primary production and litter accumulation were quantified. Temporal diversity trends were similar in both communities although the amplitude was slightygreater in Salicornia. In both communities, herbivore diversity was highest during the spring months while saprovore diversity was highest during midwinter. Predator diversity responded to both herbivore and saprovore diversity, although it was more closely tied to herbivore fluctuations in Salicornia. Standing crop biomass was maximum during Oct. and litter accumulation was highest during Jan. Two classes of adult insects occurred: persistent species, representing a low percentage of the total species compliment, were present as adults throughout the year in both marsh communities; seasonal species, on the other hand, were present as adults only during the growing season. Seasonal succession in species of herbivores and saprovores reflected productional and transformational changes in plant matter; predators responded likewise, but more impressive was the numerical response to prey populations by particular predators. Correlations were high between each trophic group and its respective resource. Physical microenvironmental factors, especially temperature and vapor pressure deficit, seemed to be important in cuing larval development, but did not exert a dramatic effect on adult diversity trends. Several strategies of habitat utilization are considered. It is hypothesized that the persistent and seasonal species have evolved as specialists to avoid competitive interactions and maximize resource utilization. During annual

expansion of resource states, the salt marsh insect component undergoes "species packing" wherein additional species enter the system temporarily to utilize the expanded resource base.

Eaton, F. M., and Bernardin, J. E. (1962). Soxhlet-type automatic sand cultures, Plant Physiol. 37: 357.
The design of an automatic sand culture system is shown. The substrate is flushed several times during each 15-minute "on" period of the time clock. Changes in the composition of the substrate are minimized by the repeated flushing of the root zone.

Harty, R. L. and McDonald, T. J. (1972). Germination behavior in beach spinifex (Spinifex hirsutus Labill.), Aust. J. Bot. 20(3): 241-251.
This paper deals with threshing and seed germination studies on hand-harvested beach spinifex. This work was carried out as part of a detailed study of the autecology of beach spinifex, an important pioneer sand stabilizer on beaches and dunes along the coast of eastern Australia. Hammer-milling was suitable for threshing out caryopses from beach spinifex inflorescences, but in the process the caryopses were excessively damaged. A barley de-awning machine produced spikelets (caryopses enclosed in lemma, palea, and glumes plus the base of the associated spine) which were free flowing and therefore suitable for mechanical planting. Laboratory germination experiments disclosed that the caryopses were negatively photoblastic when germinated alone, or enclosed within the spikelet. Alternating thermoperiods (10-25, 15-25, 20-25; 10-35, 15-35, 20-35°C) were generally superior to constant thermoperiods (25, 30, 35°) in the induction of germination. The germination of caryopses from inflorescences harvested 2 mo. previously agreed with an estimate of viability made by using tetrazolium chloride. This indicated that beach spinifex seed has no pronounced after-ripening requirements. The rate of germination of caryopses and their germinative capacity were markedly increased when the caryopses were removed from the spikelets. It is likely that germination in the spikelet is inhibited by a slow rate of gaseous exchange between the embryo and the atmosphere. A sensitivity to anaerobic conditions was demonstrated by soaking spikelets for varying periods up to 48 hr. in distilled and sea water. Such treatments led to a decrease in germination. Pot trials showed that in waterlogged sand, no appreciable germination occurred below 3.75 cm. In sand held at field capacity, some germination occurred down to the maximum depth tried (8.75 cm), but the best germination was from 2.5 to 3.75 cm. Soaking spikelets in distilled water for 48 hr. and testing the leachate on germinating lettuce seed failed to disclose the presence of water-soluble chemical inhibitors in the spikelets.

Hinde, H. P. (1954). The vertical distribution of salt marsh phanerogams in relation to tide level, Ecol. Monogr. 24: 209-225.
The marshes around Palo Alto Yacht Harbor on San Francisco Bay support three major vegetational associations: the Salicornietum with the glasswort Salicornia ambigua as the dominant, the Spartinetum with Spartina leiantha or cordgrass as the dominant and the Distichlidetum in which the salt grass, Distichlis spicata dominates. The Salicornia zone is characterized by an emergence-submergence ratio of 1.25, colonization by seed formation and peat formation. Glasswort occurs from 10.3 ft. above M.L.W. to 6.4 ft. above M.L.L.W. The Spartina zone is characterized by an

emergence-submergence ratio of 4.05 colonization by rhizomes and little, associated peat formation. *Spartina leiantha* occurs from 8.4 ft. above M.L.L.W. to 5.4 ft. above M.L.L.W. The *Distichlis spicata* zone has an emergence-submergence ratio of 0.67 and spreads mainly by rhizomes and runners. This zone occurs between 10.3 ft. and 7.15 above M.L.L.W. The vertical distribution of these seed plants is effectively controlled by the degree of tidal emergence and submergence to which they are subjected. The cordgrass at times endures a maximum submergence of 21 continuous hours at its lowest occurence. The author notes that, under conditions of well-aerated soil i. e. soil which is completely saturated with water, *Spartina* is better able to withstand longer submergence periods than *Salicornia* because of its well-developed aerenchyma. *Salicornia* is unable to extend its range lower than 6.4 ft. above the M.L.L.W. primarily due to its lack of air storage tissue. At its upper range, the glasswort abruptly disappears where man-made improvements on the marsh have raised the elevation to the point where plants of higher elevation may invade. The upper 2 ft. of the range of *Spartina* coincides with the lower 2 ft. of the range of *Salicornia*. It is believed that this coincidence is a result of a gradual increase in elevation due to reclamation activities on the marsh, and that *Salicornia* will eventually replace *Spartina* which will become increasingly restricted in occurence as reclamation continues. *Distichlis spicata* is widely distributed on the marsh but is found only occasionally in pure stands on the tops of dikes. It is distributed intermittently with *Salicornia*. It rarely occurs with *Spartina* and is unable to compete with *Spartina* in the submerged habitat.

Hubbard, J. C. E. (1965). *Spartina* marshes in southern England. VI. Pattern of invasion in Poole Harbour, *J. Ecol.* *53*: 799-813.
Population changes resulting in a pattern of invasion by *Spartina townsendii* (s.l.) in Poole Harbour have been described from a study of historical and photographic records. The origin and relationships of *Spartina* species are discussed. The basic pattern of *Spartina* marsh distribution was determined by the distribution of mudflats above O.D. (Newlyn) prior to the advent of *Spartina*. Two distinctive patterns of spread have been recognized. The first results from initial extensive seedling establishment and subsequent rapid expansion of tussocks by vegetative growth in optimum conditions on level mud and is characteristic of the early phase of development. The second results from much more limited seedling establishment on sloping mud surfaces adjoining accreting swards. It is estimated that the area occupied by *Spartina* reached a maximum of 2124 ac (867 ha) about 30 years after its initial establishment at the end of the nineteenth century. During the last 40 years the area of *Spartina* marsh has been reduced, by various factors, by about 20% of the maximum and there is evidence that the decline is still continuing. The importance of Poole Harbour as the main centre for the distribution of *Spartina* planting material is exemplified by the fact that over 175,000 plant fragments and many samples of seed have been dispatched from this area to at least 130 sites around the world.

Hubbard, J. C. E. (1969). Light in relation to tidal immersion and growth of *Spartina townsendii*, *J. Ecol.* *57*: 795-803.
The seaward spread of *Spartina anglica* may be governed by periods of immersion during neap tides rather than spring tides. The lowest level of *S. anglica* in Poole Harbour was immersed for periods up to 23 hr. duration

during neap tides, but cultured plants withstood total immersion in clear sea water for at least 4½ months. S. anglica grown in an environmental chamber flowered in a photoperiod of 16 hr.; it remained in a vegetative state when the photoperiod was only ten hours, although new shoots were most numerous when light intensity was increased. No definite link could be established between alteration in the light regime through tidal immersion and phenological changes known to occur in plants of S. anglica grown under artificial lighting conditions.

Hubbard, J. C. E. (1970). Effects of cutting and seed production in Spartina anglica, J. Ecol. 58(2): 329-334.
The common cord grass, Spartina anglica, is responsible for the major portion of seed which, in Great Britain, has resulted in the rapid extension of Spartina marshes. In this study, Hubbard subjected plots of S. anglica to cutting treatments and he also subjected seeds to storage and germination tests in which photoperiod and temperature were the major variables. The plots, which were cut to ground level (June-October, 1962, every month), bore a dense mass of flowering shoots in August, 1963, at one location (Keysworth) but the results were negative at Bridgwater Bay. Seed from the cut plots were superior in quantity, viability and germination capacity. Ninety-percent germination of collected seed occurred within 50 days under conditions of total darkness at 25°C. Exposure to light decreased percent germination. Seed increased the percent germination at lower temperatures after a one year storage period of 4°C indicating that S. anglica may require a period of after-ripening prior to germination. Percent germination increased over a range of 7°C-25°C. Hubbard observed from the control plots that the natural of older S. anglica is achieved mainly by vegetative means i.e. shoot growth and rhizomes.

Miller, W. R. and Egler, F. E. (1950). Vegetation of the Wequetequock-Pawcatuck tidal marshes, Conneticut, Ecol. Monogr. 20: 143-172.
Part A - General Abstract. The Wequetequock-Pawcatuck saline tidal marshes are a single compact area in extreme southeastern Conneticut, owned mainly by the Conneticut State Board of Fisheries and Game and administered for the research and development as a public shooting area. The vegetation is a complex mosaic of many communities and macrophyte distribution is correlated with tidal effects, varigations in salinity, surface levels, soil acidity, peat formation, compaction and disintegration. A simplified upland-to-bay sequence involves four vegetational belts: a Pancium vigatum Upper Border which is dominated by the latter species and Spartina pectinata, a Juncus gerardi Upper slope, a Spartina patens Lower Slope and a Spartina alterniflora Lower Border. Depressions are of two types: pannes and deep potholes. Pannes, closely related with evaporation and lethal salt concentrations, are associated with: more or less permanent Ruppia pools, bare salt pannes, stunted Spartina alterniflora community and forb pannes of many herbs. Potholes, of unknown genesis, appear to be enlarging in some areas and contracting in others. Estuaries are lined by Spartina alterniflora communities. Broad low natural levees frequently develop, covered with Juncus community of the Upper Slope.
Part B - Effects of Ditching, Mowing and Sheet Erosion on Salt Marsh Communities. Miller and Egler reviewed in detail the effects of mowing and ditching and the succession of communities which occurred in various types of ditches (see Fig. 16). Mosquito ditches not only produce distinctive

types at their margins, but because of drainage of pools and the development of natural levees at their sides, they have far-reaching effects on the entire mosaic of the tidal marsh. From the standpoint of vegetation, the ditches are of infinite variety and no two are exactly the same. However, Miller and Egler classified the ditches into four types: new ditches, aggrading ditches, enlarging ditches and recut ditches. The new ditch is an excavated channel about 30 cm. wide and 50 cm. deep. It is composed of a flat ditch bed and a ditch margin which is composed of peat. The turf line is the area in which turf has been piled. Aggrading ditches are those in which vegetational development gains have ascended over the eroding effects of flowing water. Spartina alterniflora extends into the ditch, serves to cut off water flow and builds up a turf fibrous root stocks. Enlarging ditches are those in which tidal flow overrides the control of the bank by vegetational processes. The ditch tends to enlarge under these conditions and this process is aided by erosion, scour and burrowing crabs. The Spartina alterniflora margins spread apart accordingly. Recut ditches are those in which the Spartina alterniflora has been removed from the margins. Certain marsh areas have also been subject to mowing activities since colonial days. Repeated mowing of the Pancium border, which is a tussock grassland, and the Juncus zone has had two major effects. First, repeated mowing destroys the spread of Pancium and Juncus into areas where the mulch of dead grass has formed compost and, second, mowing produces considerably reduced root systems. Miller and Egler conclude that the ultimate trend of vegetation in the Wequetequock-Pawcatuck salt marsh, in the absence of fire, mowing and ditching cannot be foretold with certainty.

Mooring, M. T., Cooper, A. W., and Seneca, E. D. (1971). Seed germination responses and evidence for height ecophenes in Spartina alterniflora. Amer. J. Bot. 58(1): 48-55.

A study was conducted to determine germination response to temperature and salinity and seedling response to salinity by three height forms of the salt marsh grass Spartina alteriflora Loisel. Collected seeds were removed by hand from the glumes, lemma and palea and disinfected by immersion in 25% Clorox for 15 minutes. Germination tests were carried out in petri dishes at a density of fifty seeds per plate. The seedlings were germinated from lab stocks. Germination tests demonstrated that seeds cannot withstand drying at moderate temperatures, as viability is lost within 40 days in seeds stored dry at 72°F. Cold storage at 43°F is adequate to prevent desiccation up to 40 days, but after 8 months viability is lost. Viability is retained at least 8 months when the seeds are stored in sea water at 43°F. Germination response was good in a 65-95°F alternating thermoperiod but poor in a 72°F constant thermoperiod. Germination response to salinity was an inverse curvilinear relationship with germination inhibition at high salinity apparently due to osmostic effects. The maximum tolerance limit for germination lies between 6 and 8% NaCl. Seeds from short, medium and tall plants responded similarly in storage and temperature tests. A logarithmic curve best described seedling growth response to various NaCl levels. Growth response as measured by seedling dry weight was best in 0.5% NaCl solution. Seedlings (initial height 10 cm) grew taller in both 0.5 and 1.0% NaCl than in 0% NaCl. No significant difference in seedling growth response due to height form of the parent was detected. Thus, on the basis of germination and seedling responses, the height forms of S. alterniflora

in North Carolina salt marshes are best described as ecophenes. Also, field observations demonstrated that seedlings were found in the field most often near creeks or at the sound's edge. This further substantiates that areas of lowest salinity are the most favorable for germination and seedling establishment.

Phleger, C. F. (1971). Effect of salinity on growth of a salt marsh grass. Ecol. 52: 908-911.
Young plants of the coast the salt marsh grass, Spartina foliosa Trin., were cultured for 8 weeks in nutrient solutions at different salinities (0%-125% sea water at 25% intervals). Growth and survival was greatest in fresh water. Also, laboratory induced germination was unsuccessful with such commonly used techniques as: soaking in Hoagland's solution, planting in marsh mud substrate, exposure to red light for ½ hour to 24 hours or incubation on wet cloth of 2 months. Thus, Phleger concluded that the collected seeds were non-viable. Phleger speculates that the major mode of colonization by Spartina is via dislodged rhizomes which spread via currents, tidal inundations and under storm conditions. Protein (17.9% ± 0.8%, dry weight) and lipid (16% dry weight) were higher in plants grown in fresh water than in sea water (12.4% ± 0.5% protein, 3% lipid). Fresh water plants contained less sodium (0.25%) and more potassium (3.52%) than sea water plants (4.32% sodium, 1.8% potassium).

Pojar, Jim (1973). Pollination of typically anemophilous salt marsh plants by bumble bees, Bombus terricola occidentalis Grne. Amer. Midland Nat. 89(2): 448-451.
Bumble bee pollination of six typically anemophilous flowering plant species is reported from a salt marsh on the west coast of Vancouver Island, Canada. Several other anemophiles in the marsh were not visited by the bees, apparently either because they flowered too early, or were too infrequent or pollen-poor to be attractive to the bees. The opportunistic entomophily may be of considerable significance to the six dominant species involved and, indirectly, to other subordinate elements of the vegetation.

Purer, E. A. (1942). Plant ecology of the coastal salt marshlands of San Diego County, California. Ecol. Monogr. 12: 81-111.
Twelve stations in definitely saline areas of San Diego County represent the various conditions under which the salt marsh vegetation can exist. The marshes can be placed into three groups: (1) with large bodies of water, open to ocean where salinity is nearly constant, (2) in areas where fresh water stream flow is persistant throughout most of the year causing a fluctuation in salinity which is lowered during the rainy season and (3) in areas where stream flow is intermittent causing fluctuations in which the salinity increases during summer and autumn. Purer recognizes three zones of vegetation which persist in all of these areas: (1) the lower littoral of which Spartina is the principle species, (2) the middle littoral of which Salicornia predominates and (3) the upper littoral which is composed of competing species of Frankenia, Distichlis, Atriplex, and Monanthochloe. Spartina foliosa, a xerophytic grass, with rolled leaves, propagates principally by rhizomes, stands the greatest salt water immersion and possesses abundant intercellular spaces and lacunae. Salicornia, a leafless halophyte, does not bear as much submergence although it grows in areas where the salinity is more variable.

It has a limited amount of air stored in its intercellular spaces and air-storing thracheids. Distichlis propagates by runners and rhizomes and possesses air spaces in its subsurface parts sufficient to stand some submergence. Ditching aids in the improvement of aeration and freedom from competition for plants like Spartina which have well-developed aerenchyma.

Ranwell, D. S. (1972). Ecology of salt marshes and sand dunes, Halstead Press, London-New York, pp. 258.
This book compares and contrasts the salt marsh and sand dune habitats and the ecological processes operating within them. The content is divided into 4 major sections. The first part, general relationships, discusses climatic restraints, physiography and hydrology and mineral nutrient relations. Part 2, salt marshes, discusses tidal influence; sedimentation, drainage and soil physical development; species strategies; and structure and function of communities. Part 3, sand dunes, covers formation and differentiation of the habitat; sand, water relations and processes of soil formation; structure and function of dune communities; and structure and function of slack communities. The final section, human influences, covers management of salt marsh wildlife resources and management of sand dune wildlife resources. The book ends with a comprehensive bibliography covering 400 references. The book will be of value to senior undergraduates, postgraduates, teachers and all those concerned with the use and management of salt marshes and sand dunes in any part of the world.

San Francisco Bay Conservation and Development Commission (1969), Report Supplement, Document Cal s177 s2, pp. 59-67.
This report is a summary of a more detailed report by H. T. Harvey ("Some Ecological Aspects of San Francisco Bay", 1966, s177 e2). Harvey notes that three quarters of all the marshland surrounding San Francisco Bay has been filled or diked off. He recommends rehabilitation of salt marshes by two methods. First, dikes which impede tidal flow should be removed (e.g. diked marshland of Corte Madera and salt ponds of the South Bay). Second, dredged soil could also be placed on the mud flats to raise them to an elevation at which vegetation could be established.

Seneca, E. D. (1969). Germination response to temperature and salinity of four dune grasses from the outer banks of North Carolina, Ecol. 50: 45-53.
At four constant thermoperiods (65°, 75°, 85°, and 95°F) and three alternating diurnal thermoperiods (65°-75°, 65°-85°, and 65°-95°F), good germination (above 70%) was obtained with seed of Ammophila breviligulata Fern., Panicum amarulum Hitch. and Chase., and Spartina patens (Ait.) Muhl. without cold treatment under certain temperature conditions. None of the constant temperature treatments yielded good germination. All attempts to obtain good germination with Uniola paniculata L. without cold treatment were unsuccessful. Various periods of cold treatment had no effect upon subsequent germination in the 65°-95°F alternating diurnal thermoperiod in A. breviligulata and S. patens. In P. amarulum cold treatment for 15 days was sufficient to ensure good germination. Cold treatment for 30 days was adequate for good germination in U. paniculata, but 15 days was not always sufficient. When cold treatment for 30 days at 43°F preceded germination in the seven temperature conditions, germination was increased in all species. Maximum tolerance limits for Ammophila

breviligulata and U. paniculata to NaCl lie between 1.0% and 1.5%. The upper limit of NaCl concentration for germination of P. amarulum is between 1.5% and 2.0% and for S. patens about 4.0%. Germination response to salinity was primarily an inverse linear realtionship for A. breviligulata, P. amarulum, and U. paniculata, but a curvilinear relationship in S. patens. In this species germination was successful at 2.0% NaCl. Germination inhibition in A. breviligulata, P. amarulum, and S. patens was apparently primarily an osmotic effect. Based on germination response, S. patens is the most salt tolerant, followed by P. amarulum which is more tolerant than U. paniculata. A. breviligulata is the most salt sensitive.

Seneca, E. D. (1972). Seedling response to salinity in four dune grasses from the outer banks of North Carolina, Ecol. 53: 465-471.
Tolerance to salt in the substratum was determined in seedlings of four perennial dune grasses: Ammophila breviligulata Fern., Panicum amarulum Hitch. and Chase., Spartina patens (Ait.) Muhl., and Uniola paniculata L. An inverse linear relationship existed between growth and increased salinity in A. breviligulata, S. patens, and U. paniculata. Panicum amarulum seedlings demonstrated a curvilinear response to salinity. Seedlings of A. breviligulata and U. paniculata grew moderately well in salinities up to 1.0% NaCl, those of P. amarulum achieved even better growth in this salinity range, and some seedlings of S. patens survived the entire 28-day experimental period at 4.0% NaCl. Seedlings of S. patens collected from the field were more salt tolerant than those grown from seed collected from the field and germinated in the laboratory. In the other species the performance of field- and laboratory-grown seedlings did not differ. Based on seedling growth response, the order of decreasing salt tolerance for the four species is S. patens, P. amarulum, U. paniculata, and A. breviligulata. This pattern correlates well with performance in nature.

Sivanesan, A. and Manners, J. G. (1972). Bacteria of muds colonized by Spartina townsendii and their possible role in Spartina die-back, Plant and Soil 36: 349-361.
A study of the bacterial microflora of muds colonized by Spartina townsendii agg. in healthy and "die-back" sites in the Lymington estuary was made. No important qualitative differences were found between the microfloras of the 2 types of site. Fewer species, however, were present in the die-back sites. It is suggested that under anaerobic conditions, such as occur in a "die-back" site, the bacteria will utilize such O_2 as is present, and will then engage in anaerobic metabolic processes, producing reduced ions which will reduce the oxidation-reduction potential still further. The occurrence of abundant sulfate reducers in the "die-back" sites may be particularly significant in this respect. No evidence was obtained of any more direct relationship between bacterial flora and the development of "die-back".

Stalter, R. and Batson, J. (1969). Transplantation of salt marsh vegetation, Georgetown, South Carolina, Ecol. 50: 1087-1089.
A salt marsh located on the Baruch plantation at Georgetown, South Carolina is comprised of four vegetation zones (HH marsh, LH marsh, HL marsh and a LL marsh). Thirty plants of each of the dominant species in each zone were transplanted into the other three zones. Thirty plants of the

dominant species were also transplanted within each zone to serve as controls. The plants were moved during the dormant season (late Nov.-Dec., 1967) and placed into soil plugs of 20 cm^3 so as to reduce the trauma of transplantation. Data on the survival of the tall, leafy form of Spartina alterniflora suggests that this species is unable to tolerate the xeric conditions of the HH marsh. The distribution of Spartina alterniflora and Spartina patens is limited by chlorinity, duration and depth of tidal flooding and inter-and intraspecific competition. Salicornia virginica appears to thrive best in areas of high soil solute concentration and in which there exists prolonged periods of flooding.

Teal, J. M. and Kanwisher, J. W. (1966). Gas transport in the marsh grass Spartina alterniflora, J. Exp. Bot. 17: 355-361.
Spartina plants have continuous gas spaces from the leaves to the tips of the roots. Oxygen values in the roots are as low as 3 per cent and increase toward the stem. Carbon dioxide values are highest in the rhizome and decrease up the stem and toward the root tips. Oxygen and carbon dioxide moved through the plants at equal rates for equal gradients, and these rates agree with measurements made on plants in the marsh. Calculated oxygen and carbon dioxide fluxes for the observed gradients in the observed gas spaces agreed with measured fluxes. We include that gases move in and out of Spartina roots by diffusion through uninterrupted gas spaces within the plant.

Teal, J. M. and Kanwisher, J. W. (1970). Total energy balance in salt marsh grasses, Ecol. 51: 690-695.
Leaf temperature in Spartina alternifolia and S. patens varies little from the ambient air temperature. Spartina leaves lose from 70 to 460 molecules of water for every molecule of CO_2 taken out of the air. This loss of water is consistent with the hypothesis that gases move between the air and the leaf by simple diffusion. There is evidence of a lowered water potential at the evaporating surface within the leaf.

Udell, H. F., Zarudsky, J., Doheny, T. E., and Burkholder, P. R. (1969). Productivity and nutrient values of plants growing in the salt marshes of the Town of Hempstead. Long Island, Bull. Torrey Bot. Club 96: 42-51.
The abundance and chemical composition of marsh grasses, sea lettuce and phytoplankton were determined in the Hempstead Bay estuary of the Town of Hempstead, Long Island, New York in 1967. The marshland comprises about 6,700 acres and the aquatic environment some 11,500 acres. Species of marsh grasses belonging in the genera Spartina and Distichlis produce an estimated 17,113 tons of dry matter per year in the Hempstead estuary, while the aquatic sea lettuce and phytoplankton produce 21,955 tons. The primary producers of organic matter in the Hempstead estuary are shown to form valuable quantities of protein, fat, carbohydrates and vitamins. Protein content of marsh grasses ranged from 9.6% to 14.9% of dry weight. Zostera yielded 14.6% and Ulva 20.8% protein in the dry matter. In the species of Ulva, Zostera, Spartina and Distichlis ash content varied from 5.5% to 58.2%, fat ranged from 0.5% to 2.9% and carbohydrate yielded from 18.2% to 63.9%. Four B vitamins were present in adequate amounts to satisfy the requirements of grazing animals and microorganisms. Vitamin B_{12} occurred in relatively small amounts, (0.008 to 0.022 microgm/gm) in the flowering plants, but Ulva yielded 0.26 microgm of B_{12} per gram of dry matter. These nutrients and essential growth factors are available

for direct assimilation by herbivores, and through microbial transformation to detritus they also supply indirectly valuable stores of particulate matter for filter feeders and other marine life.

Vogl, R. J. (1966). Salt-marsh vegetation of upper Newport Bay, California. Ecol. 47: 80-87.
The salt-marsh vegetation of Newport Bay was separated into littoral and maritime zones and was sampled quantitatively for frequency of occurrence and cover. The littoral zone (marsh proper) was divided into a narrow lower belt covered by Spartina foliosa, a broadest middle band dominated by Batis maritima and Salicornia virginica, and a narrowest upper strip influenced by Salicornia virginica and Monanthochloe littoralis. The maritime zone consisted of a bluff community composed of Suaeda californica and Salicornia subterminalis, or a dune association pioneered by Oenothera cheiranthifolia and Heterotheca grandiflora. Nine species, principally Gramineae and Chenopodiaceae, dominated the marsh. Salicornia virginica accounted for the highest total average frequency and cover. Additional important species were Suaeda californica, Batis maritima, and Spartina foliosa. The plant community was extremely simple in the lowest areas (four species) and graded to a more complex, yet relatively simple plant community in the highest regions of the marsh (15 species). Correspondingly, the lower zones had sparse vegetational cover and the higher zones supported heavier growth, both in size and numbers of individuals. Although the marsh was subjectively divided into zones, individual species could not be readily segregated into zones since the frequency of each species varied along environmental gradients to produce a vegetational continuum.

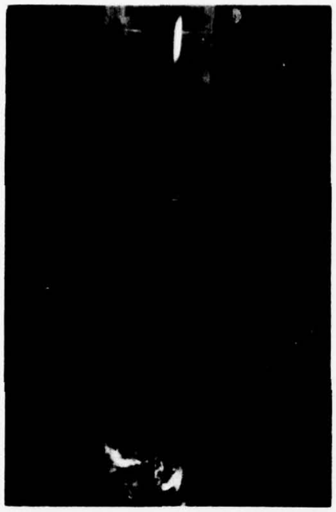
Williams, M. D. and Ungar I. A. (1972). The effect of environmental parameters on the germination, growth, and development of Suaeda depressa (Pursh) Wats, Amer. J. Bot. 59(9): 912-918.
A study was made to determine the effect of environmental parameters on the germination, growth, and development of Suaeda depressa (Pursh) Wats. Germination tests showed that seeds germinated in solutions containing up to 4% NaCl with no toxic effects indicated after treatment with distilled water. The rate of germination and the percentage germination decreased with increased salinity. The effect of environmental parameters on growth was measured by shoot height, side shoot development, leaf length, and dry weight. Growth was greatest in 1% NaCl solutions with adequate available nitrogen. With increased salinity and low available nitrogen levels plant growth decreased. A 10-hr. photoperiod stimulated immediate floral induction. Although flowering and completion of the life cycle occurred in solutions containing up to 4% NaCl, increased salinity decreased the rate of floral induction and the dry weight of flowers and fruit produced. This study indicates that environmental parameters such as salinity, available nitrogen, and photoperiod can create a variety of growth forms, causing taxonomic confusion.

Woodhouse, W. W., Jr., Seneca, E. D., and Broome, S. W. (1972). Marsh building with dredge spoil in North Carolina, North Carolina State University at Raleigh Agricultural Experiment Station Bulletin 445.
Work was initiated in the fall of 1969 along the North Carolina coast on the stabilization of dredge spoil with Spartina alterniflora Loisel. Studies included methods of propagation and establishment, growth rates,

factors affecting growth, and substrate and elevational effects. Reasonably satisfactory methods and procedures have been developed and some tentative guidelines formulated for the use of this plant for stabilization of dredge spoil.

VII. Index to Tables, Figures and Plates

PLATE I



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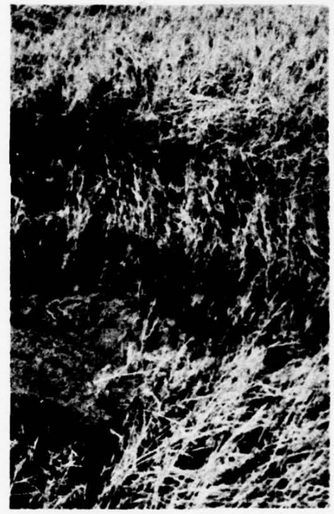

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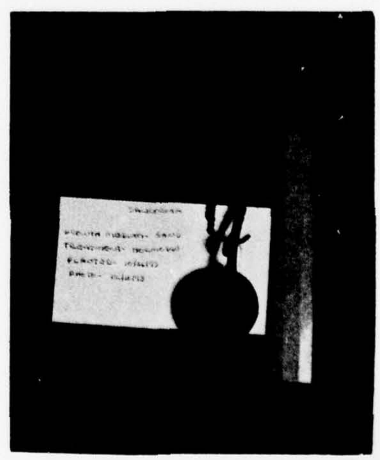

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PLATE II

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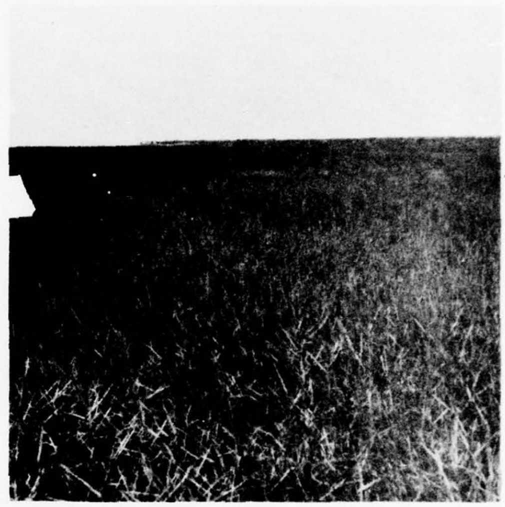

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APPENDIX A

COST ANALYSIS BREAKDOWN

A breakdown of the costs incurred during the production of Spartina and Salicornia plants in Phase I of the marsh project is herewith provided. This information we hope will prove valuable in planning the future of the project (Tables 1 and 2).

The cost analysis includes only those expenses directly incurred in the production of the plants. These expenses include labor for locating and collecting plant material, preparing plants for the nursery, potting, and maintenance; soil, fertilizers, hormones, pots, truck rental, utilities, water and other expendable items; and that portion of the supervisor's time needed for the nursery operations. Costs for laboratory maintenance and initially setting up the nursery area, and costs for work other than plant propagation are excluded from this cost analysis.

In the production of materials for Phase I the relative costs of producing propagules are necessarily higher than those projected for further work since the study was deliberately kept small to keep costs low. However one can increase production greatly with much smaller costs, since only the lowest level of labor costs go up while higher level personnel costs remain the same or in some levels are not necessary. Hence costs per plant go down due to the proportion of administrative cost to that of labor.

Furthermore, much was learned about producing propagules which could increase their survival rate while still keeping the operation economically feasible. In the transplantation process, Spartina cuttings

need to be relatively free of soil to reduce cost. However, to reduce undesirable plant shock, at least some of the original soil should be left undisturbed around the roots. Salicornia seed need not be threshed, this being a time-consuming process. The inflorescences containing mature seed could be broken up and planted.

Like all production operations, a big operation can find many ways of cutting costs.

Salicornia seedlings, except in the germination experiments, were not included in the cost figures. Well over 1500-2000 seedlings came up in the cutting beds and would significantly reduce the cost value per plant if added in the above analysis. They have not as yet been transplanted but I suspect the cost figure would be reduced by as much as 20% if they were included. This is a very conservative estimate.

Phase II operations will have a cost advantage over Phase I since it is anticipated that the operation will have the advantage of spring growing conditions rather than the adverse growing conditions of coming dormancy.

TABLE 1

COST ANALYSIS FOR PRODUCTION OF PLANTS IN PHASE I*

Treatment	Cuttings: Spartina	Cuttings: Spartina and hormone	Cuttings: Salicornia	Cuttings: Salicornia and hormone	Seed: Spartina
# tanks/ treatment	2	10	1	7	3
Average # plants/tank	340	340	400	400	***
Labor ($/tank)					
Collecting	42	42	32	32	15
Making cuttings/seed	35	35	17	17	10
Mixing substrate and filling pots	20	20	20	20	20
Hormone treatment	-	5	-	5	-
Planting	15	15	15	15	4
Maintenance**	33	33	33	33	33
Total	145	150	117	122	82
Expendable supplies ($/tank)	19	20	19	20	19
Supervision** ($/tank)	43	43	43	43	43
Total Expenses ($/tank)	207	213	179	185	144
Cost/plant (¢)	61	63	45	46	-

Total labor	3,007
Total expendable supplies	454
Total supervision	989
Total expenses	4,450
Total # of plants	7,280
Grand Average cost/plant	61¢

* Some figures are averaged over 23 tanks from total costs
** Based on a time period of 4 months
*** Seeds have not germinated as of 12/31/73

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TABLE 2

PROJECTED COST ANALYSIS FOR FUTURE PRODUCTION OF PLANTS*

Treatment	Cuttings		Seedlings
	Spartina	Salicornia	Spartina
Average # plants/tank	360	440	***
Labor ($/tank)			
Collecting	20	15	15
Making cuttings or seed	20	15	15
Mixing substrate and filling pots	20	20	20
Hormone treatment	-	-	-
Planting	15	15	5
*Maintenance***	15	15	15
Total	90	80	65
Expendable supplies ($/tank)	14	14	14
Supervision** (#/tank)	22	22	22
Total Expenses ($/tank)	126	116	101
Cost/plant	35¢	26¢	***

*Some figures are averaged over 23 tanks from total costs
**Based on 2 months time period when an extensive operation is underway
***Depends on success of germination

APPENDIX B

SURVIVAL OF GERMINATED SEEDS
SPARTINA

SAN FRANCISCO BAY
MARINE RESEARCH CENTER, INC.
Marine Ecosystems • Pollution Abatement • Scientific Aquaculture

POINT SAN PABLO LABORATORY
WESTERN DRIVE EXTENSION
RICHMOND, CA. 94804
(415) 232-5100

MAILING ADDRESS
8 MIDDLE ROAD
LAFAYETTE, CA. 94549
(415) 254-5650

April 1, 1974

MEMORANDUM

TO: Paul Knudsen, A C E
FROM: Curtis Newcombe, M R C
SUBJECT: Survival of germinated seeds - Spartina

1. Project Office Experiment - Inside
   Germinated seeds from petri dishes planted in sand in January
   Showed 80% survival on April 1, 1974
   Average height = 2.2 cm
   Substrate: sand, water fresh.

2. Mezzanine Experiment - Inside
   Germinated seeds similarly gave 80% survival out of a total of 235
   Substrate: sand, water-fresh.

3. Outside - Tank E5.
   Seeds germinated inside greenhouse at Mills College in January; transplanted outside at MRC on March 6/74
   Only grew slowly in greenhouse
   Since March 6 they have grown well, present average height of ones with true leaves is 2 to 2.5 cm
   Survival = 86% of a total of 248 seedlings
   Substrate = 2/3 sand plus 1/3 mud (dredge spoil) with fresh water

4. Outside - Tank B4
   Seed germinated inside greenhouse at Mills College in January 1974
   Planted March 8/74 at M R C
   Survival = 82% out of a total of 320 seedlings
   Substrate: 2/3 vermiculite plus 1/3 sand and mud(dredge spoil)

5. Outside - Tank B5
   Seed germinated inside greenhouse at Mills College in January 1974
   Planted March 4 - 8, 1974
   Survival = 68% out of a total of 260 seedlings
   Substrate = 1/3 sand, 1/3 germuculite, 1/3 mud (dredge spoil)

6. Outside - Tank D5

Seed placed in jiffy pots filled with sand on Nov. 20/73 and covered with fresh water continuously since then.

Some seeds floated, some stayed on the bottom

Some have rooted into the sand - 800

Some have remained afloat and germinated - 2000

About 3000 other seeds and/or chaff remain on the bottom. Only about 1/3 of these appear to be alive.

The 2800 germinated seeds started to germinate in late January and reached a peak in February.

By March 21/74 about 200 more had germinated indicating a slower rate of germination. The floating gerinated seeds appear healthy.

Data are available on percent germination in petri dishes to supplement tabular data given on pages 60 and 62 of Dr. Mason's report.

INCLOSURE TWO

SAN FRANCISCO BAY AND ESTUARY DREDGE DISPOSAL STUDY

MARSH DEVELOPMENT STUDY

PHASE TWO - PILOT STUDY

by
Dr. Curtis L. Newcombe and Charles R. Pride
S.F. Bay Marine Research Center, Inc.

MARSH STUDIES

THE ESTABLISHMENT OF INTERTIDAL MARSH PLANTS

ON DREDGE MATERIAL SUBSTRATE

by

Curtis L. Newcombe and Charles R. Pride

February 1, 1975

Point San Pablo Laboratory
San Francisco Bay Marine Research Center, Inc.
Richmond, California
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1975

THE ESTABLISHMENT OF INTERTIDAL MARSH PLANTS ON DREDGE MATERIAL SUBSTRATE

by

Curtis L. Newcombe* and Charles R. Pride**
Project Director / Research Associate

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*Director and Chief Scientist, San Francisco Bay Marine Research Center.
Professor-Emeritus of Biology, San Francisco State University

**Laboratory Supervisor, SFBMRC, Inc.

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THE ESTABLISHMENT OF INTERTIDAL MARSH PLANTS

ON DREDGE MATERIAL SUBSTRATE

I. INTRODUCTION

Increasingly, the importance of providing new marshland biotic communities as well as the restoration of once highly productive intertidal marsh habitats is being recognized by the public and by agencies of government. In 1911, G. M. Warren of the U. S. Department of Agriculture pointed out that man has been adapting intertidal marshlands for agricultural purposes since antiquity (Warren, 1911). Information of great practical as well as historical interest bearing on the marshland environments, and marsh plant-animal associations was assembled by Chapman (1960). More recently, in "Ecology of Halophytes" edited by Reimold and Queen (1974), important contributions to knowledge of the biota of marshes are presented. But many questions still remain unanswered. MacDonald and Barbour (1974) emphasize that the salt marshes of northern California are "only poorly known." They estimate that 55 percent of the approximate 56,000 acres of California salt marshes are in San Francisco Bay.

The need for suitable land disposal sites for placement of Bay Area saline dredge disposal materials has been recognized by the U. S. Army Corps of Engineers. Also, the importance of having a capability for producing, as rapidly as possible, an adequate plant cover has not been overlooked by the Corps (Woodhouse, Seneca and Broome, 1974).

To help meet the afore-mentioned requirements for marsh vegetation cover, the San Francisco District Office of the Corps of Engineers contracted with the San Francisco Bay Marine Research Center for biological studies on marsh grass culture under laboratory and field conditions. The laboratory studies were conducted during the period, August 1 -

December 31, 1973 (Mason, 1973). The field studies, which are reported here, were performed during 1974 at an intertidal site on the north side and near the mouth of Alameda Creek situated on the east side of South San Francisco Bay (Lat. 37° 34' N, Long. 122° 07' W), (plates 1 and 2).*

II. BACKGROUND INFORMATION

A. Habitat Conditions.

Assessment of the feasibility of inducing native plant species to grow on newly positioned sediment substrate is essentially an ecological project. At Alameda Creek, factorial ingredients are:

1. Soil Type. The usefulness of sediment substrate for growing marsh plants is a function of certain physical characteristics and chemical properties. Dredge materials, long termed dredge spoil reflecting its reputation as environmentally detrimental, may or may not be conducive to favorable growth conditions. Here, lack of confinement and a favorable location for periodic drainage and aeration are positive considerations to enhance wildlife habitat. But it remains to measure the particle size distribution in the soil, the stability of the soil layers and their erosion potential, and the E_h or oxidation-reduction potential of the substrate both adjacent to and away from the cordgrass rhizomes and roots which contribute to the aeration of the subsurface habitat that is predominantly anaerobic. Other parameters to be considered are: the organic carbon and moisture contents of the soil; its alkalinity, chlorinity or salinity, and nutrient contents; and also its content of heavy metals. Upon these physical-chemical parameters may depend the establishment, growth, and survival of plant-animal communities.

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*A Study conducted under Contract Number DACWO-7-74-C-0008, Modification No. P002 for the U. S. Army Corps of Engineers, San Francisco District.

a b

Plate 1. Showing the Alameda Creek Experimental Area in South San Francisco Bay in May, a, and in October, b, 1974. Note the irregularity of the terrain, and the plot markers.

Plate 2. Showing the marsh grass nursery at the Point San Pablo Laboratory of the San Francisco Bay Marine Research Center.

2. Marsh Elevation. Intertidal elevation is perhaps the major single factor determining the presence, growth, and survival of brackish water and marine organisms. Viewed from the distance, a drop of one (1) centimeter in vertical intertidal level may mark the complete absence of an alga or a mollusc or a barnacle. Little wonder then, that students of San Francisco Bay salt marsh phanerogams, such as Hinde (1954) and Harvey (1966), have devoted special attention to the vertical distribution of the flowering plants of the Bay marshes, particularly in respect to marsh restoration. The first North American study of intertidal plant zonation in relation to actual tidal amplitude was the classical work of Johnson and York (1915) at Long Island, N. Y. Intertidal zonation of the dominant plant-animal communities of the Bay of Fundy region was described by Newcombe (1935).

Spartina foliosa Trin. and Salicornia pacifica Standl. are the dominant local plants for which information is needed on upper and lower vertical extremes of distribution and mean distribution levels as well as ratios of submergence to exposure time. (Plates 3, 4, and 5; and Appendix B). The lower intertidal zonation of Spartina, in relation to Salicornia, is commonly attributed to the presence in the genus of aerenchyma tissue that enables it to endure longer submergence. In this study for the Corps of Engineers, the morphology of this particular tissue was studdied by Professor Baki Kasapligil (Appendix C).

Since cordgrass is believed to be in point of origin a land plant that has become adapted increasingly to saline conditions, a vertical level well above a low water level (Mean Tide Level, e.g.) would be favorable ecologically for survival and growth (Table 1). For example, Professor H. Thomas Harvey states that cordgrass can survive down to about 2 feet (0.6 meter) above MLLW in South San Francisco Bay or 2 feet (0.6 meter)

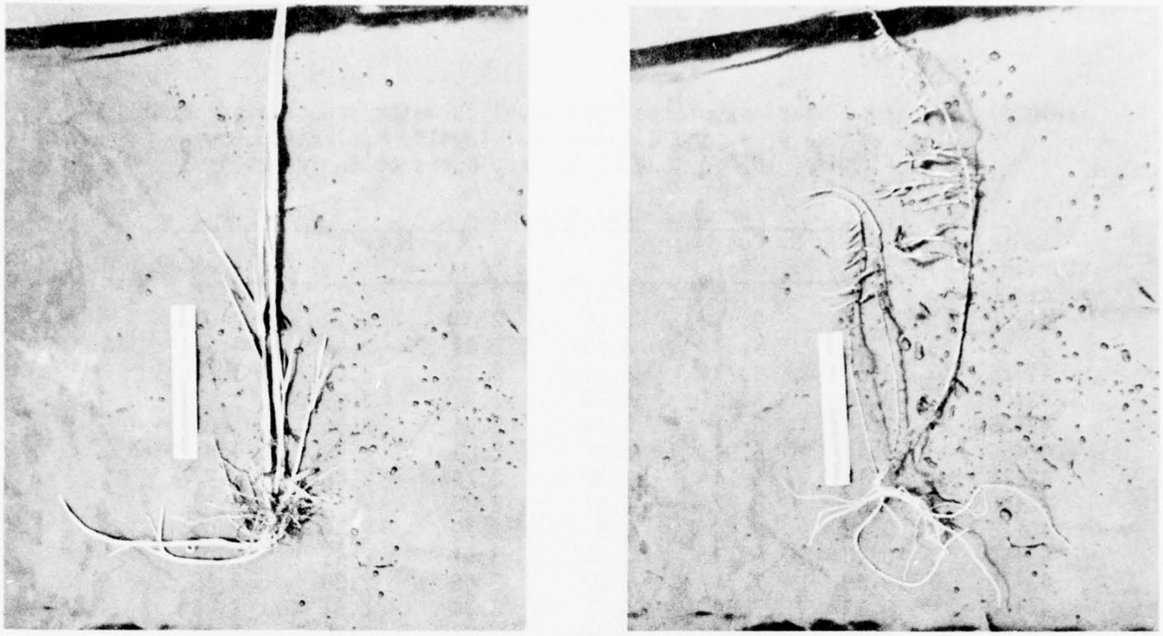

Plate 3. Showing the relative sizes of the stems and roots of Spartina foliosa Trin. (left) and Salicornia pacifica Standl.

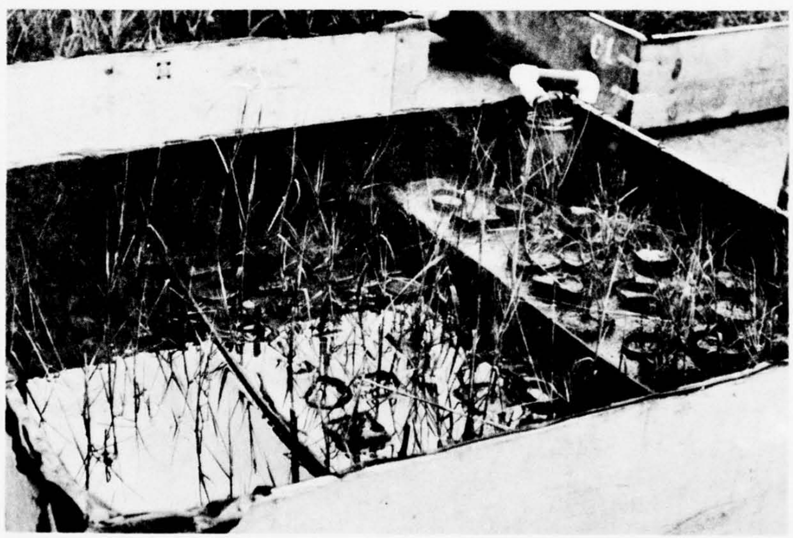

Plate 4. Showing an experimental growth box with plantings of robust and dwarf ecophenes of Spartina foliosa Trin. at three elevations providing 3 degrees of submergence times of roots from continuous to one-third.

Table 1. Showing elevations of the individual 25 meter square experimental plots at the A, B, and C intertidal levels. (Elevations were taken in May, 1974 by the U. S. Army Corps of Engineers.)

	Numerical Systems					
	U. S. Customary			Metric		
Stations	A	B	C	A	B	C
41+00	9.04	8.85	8.41	2.75	2.70	2.56
41+25	9.32	9.11	6.59	2.84	2.78	2.01
41+50	9.31	8.37	6.03	2.84	2.55	1.84
41+75	9.83	8.73	6.11	2.30	2.66	1.86
42+00	9.78	8.82	6.79	2.98	2.69	2.07
42+25	9.64	8.41	6.74	2.94	2.56	2.05
42+50	9.46	8.94	6.27	2.88	2.72	1.91
42+75	9.14	8.14	7.45	2.79	2.48	2.27
43+00	9.20	8.27	6.82	2.80	2.52	2.08
43+25	9.15	8.00	6.61	2.79	2.44	2.01
43+50	10.20	8.13	6.80	3.11	2.49	2.07
43+75	9.39	7.71	7.07	2.86	2.35	2.15
44+00	9.33	7.59	6.71	2.84	2.31	2.04
44+25	9.26	7.21	6.48	2.82	2.20	1.97
44+50	9.09	7.51	6.80	2.77	2.29	2.07
44+75	9.39	7.70	6.56	2.86	2.35	2.00
45+00	9.68	8.13	6.92	2.95	2.48	2.11
45+25	11.56	8.15	7.13	3.52	2.48	2.17
45+50	9.71	7.90	7.21	2.96	2.41	2.20
45+75	10.03	8.47	7.20	3.06	2.58	2.19
46+00	10.43	8.49	6.88	3.18	2.59	2.10
46+25	9.94	7.91	6.84	3.03	2.41	2.08
46+50	10.06	8.00	7.47	3.07	2.44	2.28
46+75	8.97	8.95	7.28	2.73	2.73	2.22
47+00	11.00	9.56	7.22	3.35	2.91	2.20
47+25	10.84	7.98	6.81	3.30	2.43	2.08
47+50	9.86	7.77	6.35	3.00	2.37	1.93
47+75	10.85	7.67	6.46	3.31	2.34	1.97
48+00	11.01	7.07	6.85	3.36	2.15	2.09
48+25	11.50	7.64	7.00	3.50	2.33	2.13
48+50	10.88	8.18	7.62	3.32	2.49	2.32
$\overline{m}$	9.90	8.17	6.89	3.00	2.49	2.10

below NGVD,* 1929 (Appendix B).

Regarding Salicornia ambigua, presumably our S. pacifica, Hinde (1954) gives a vertical range of 4' (1.2 m) its upper and lowest levels being 10.3" (3.14 m) and 6.4' (1.95 m), respectively, above MLLW and its emergence-submergence ratio 4.05.

3. Plant Species. Cordgrass, Spartina foliosa Trin., and glasswort or pickleweed, the project species, Salicornia pacifica Standl., provide practically all the plant cover in the intertidal area considered here. They are widely distributed in the fifty thousand or more acres of salt marsh along the California coast (McDonald and Barbour, 1974). One of the earliest, if not the earliest, published plantecology studies of California marshlands dealt with these species in San Diego County (Purer, 1939).

Significant to this study of dredge material, for purposes of plant cover and surface stabilization, is the fibrous composition of the cordgrass root system that forms a dense maize of short, tough roots intertwining in the shallow subsurface soil layers. The local dominant picklewood, Salicornia pacifica, is likewise a perennial and also has fibrous roots, but they are not extensive. This perennial species frequently invades bare areas of marsh where there is favorable aeration, high salinity notwithstanding. It lacks the aerenchyma tissue that enables cordgrass to exist under more rigorous anaerobic conditions at lower intertidal levels (Appendices B, C, D).

B. Early Marsh Studies

Early students of marsh plants and of the environmental factors affecting their survival and growth on intertidal substrates worked with other species of Spartina long the Atlantic coasts of Europe and America (Cooper, 1926; Miller, Ramage, and Lazier, 1928; Purer, 1936, 1942;

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*NGVD, 1929 - National Geodetic Vertical Datum established in 1929.

Chapman, 1938; Reed, 1947; Hinde, 1954; and Phleger, 1971).

Until recent years relatively few attempts have been made in the United States to plant bare intertidal marsh areas with cordgrass, the dominant marsh grass in such estuarine habitats.

The biological tools of the study to induce plant cover of bare marshland include transplants of mature plants of Spartina foliosa, (plate 3). Among the earliest studies in the United States were those conducted at Wachapreague, Virginia during 1940-1945 by Curtis L. Newcombe and associates. Over 15,000 transplants of Spartina alterniflora Lois. with the ribbed mussel, Modiolus demissus were made on two acres of salt water marsh (Newcombe, 1940-45). The transplants ("tumps") were obtained from a low marsh and transplanted to higher intertidal levels.

In 1967-68, Statler and Batson (1969) transplanted several species of salt marsh plants including S. alterniflora and Salicornia virginica near Georgetown, S. C. Transplantation studies of cordgrass, S. alterniflora Lois, have been in progress since about 1969 in North Carolina and Maryland by Woodhouse, Seneca, and Broome (1974), and Garbisch, et al, (1973). As early as 1969, Professor H. Thomas Harvey of San Jose State University initiated transplant studies of S. foliosa Trin. in south San Francisco Bay. He demonstrated excellent survival of this species on dredge material with a growth in diameter per "plug" of about 3 meters during an 18-month period. Subsequent studies by Harvey and others at the Alameda Creek, south San Francisco Bay location, are reported here (Appendix B).

The important marsh plant studies by Hinde (1954) were conducted on the Palo Alto marsh situated on the west side of the Bay about opposite Alameda Creek. He states that salt grass is present in abundance often mixed with Frankenia grandifolia, Jaumea carnosa, rarely with stands of

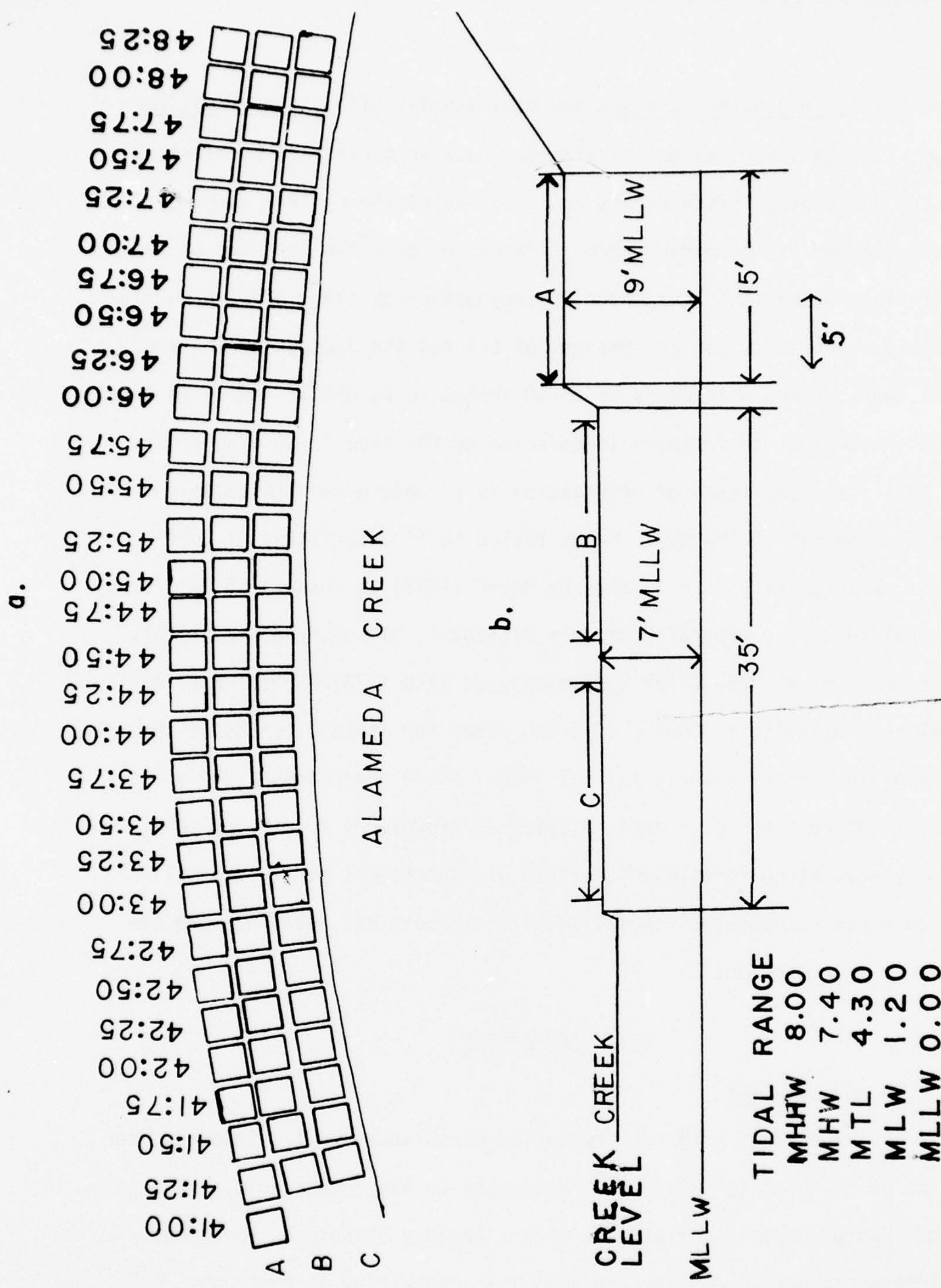

Plate 5. A diagram of plot locations and an outline of intertidal elevations of a transect intersecting plots at the A, B, and C levels of Alameda Creek.

arrow grass, _Triglochin maritima_ and occasionally with _Limonium californicum_. In the lower reaches of Alameda Creek cordgrass and pickleweed are the dominants. Hinde refers to cordgrass as the pioneer plant on the lowest reaches of the marsh where it "advances onto the soft mud of the tidal flats where it is subjected to innundation by every tide, grows luxuriantly along the sides and bottoms of all but the deepest drains and forms dense stands with canes up to 40 inches in height in low-lying areas which are subject to frequent innundation by the tide." He also points out that its major means of propagation is by underground rhizomes which form a dense mat in the mud. Hinde failed to find seedlings of cordgrass. Viable seeds were located by Mason (1973) in Phase I of this study. Mr. Paul Knutson, Corps of Engineers Biologist, has observed relatively large areas of Alameda Creek bottom covered with 1973-74 seedlings that developed following a damming of fresh water for about 3 months at the mouth of the Creek in early fall of 1973. These observations are of particular interest since, whereas pickleweed reproduces readily by seed, rapidly populating fertile soil within its intertidal range, the California cordgrass propagates vegetatively in the main and seedlings are believed to be uncommon.

III. OBJECTIVES

A. General

Widespread needs for restoring marshlands and for properly disposing of dredge materials direct attention to the conservation potential of the bottom deposits of stream, river, and bay channels. To assess the environmental usefulness of such deposits a knowledge of their physical and chemical properties is essential. Also, the possible need for using fertilizer to enhance marsh plant growth has to be evaluated, and the role

of heavy metals in affecting growth must be known.

B. Specific

The primary objectives of this study have been: (1) to develop a better understanding of the environmental conditions that influence the growth of intertidal cordgrass, Spartina foliosa Lois. and pickleweed, Salicornia pacifica Standl.; (2) to analyze the suitability of substrate material for producing the aforementioned plants; and (3), to provide factual guidelines on which to base an efficient and inexpensive means for planting dredge material substrate with these plant dominants.

The physical and chemical analyses of the dredge material substrate used in the environmental study include heavy metal analyses and particularly the submergence-emergence ratios at pertinent intertidal elevations (Appendix B).

Objectives have included measurements of several indices of environmental suitability. Indices of plant response used to assess environmental suitability are: linear growth and/or survival of seeds, seedlings, cuttings, and "plugs."

Indices of habitat favorability employed include the rate at which typical marsh infauna become established.

Additional objectives of the investigation are: (1) to contribute to a better understanding of the anatomy and oxygen-producing capacity of Spartina foliosa Lois. that facilitate its existence in relatively anaerobic substrates (Appendices C and E); (2) to extend knowledge of the genetic relationships between the tall growth form (robust) and the short growth form (dwarf) of the local cordgrass (Appendix D); and (3) to conduct a cost analysis of the factors involved in the development and rehabilitation of the Alameda Creek marsh area.

IV. SCOPE OF WORK

The historical findings that pertain to the ecology of marsh plants and the practical problem of how best to produce vegetation on dredge material have largely determined the scope of this investigation. The biological phases embraced efforts to demonstrate survival and growth of cordgrass seeds planted at different levels; of seedlings and rooted cuttings of nursery stock of cordgrass and pickleweed (glasswort); and of cordgrass "plugs" (both dwarf and robust ecophenes) transplanted from pure stands in nature. The investigation has included a special intertidal transect study of the differences in growth and survival of dwarf (short growth form) and robust (tall growth form) ecophenes of cordgrass. There is the often-raised question as to whether these two forms are products of environmental differences or of genetic variation (Appendices B, C and D).

At Alameda Creek, the most pertinent environmental factors to successful plant development on bare dredge material are: intertidal elevations adequate for plant cover, nature of the substrate, water-soil salinity content, and the chemical composition and physical properties of the soil. The biotic considerations are: (1) the developmental stages or anatomical parts or community aggregations ("plugs" or "tumps") of the plants used for producing the desired plant cover; and (2) the associated animals - infauna and onfauna.

The 1973 marsh plant studies of this laboratory, monitored by Mr. Paul Knutson of the Army Corps of Engineers, included the establishment of a marsh nursery for the production of local species of cordgrass and pickleweed (Mason, 1973); (Plate 3). Seeds were collected in the fall of 1973 by Mr. John Jackson, et al, and stored over-winter in preparation for the 1974 planting operations at the Alameda Creek intertidal site of

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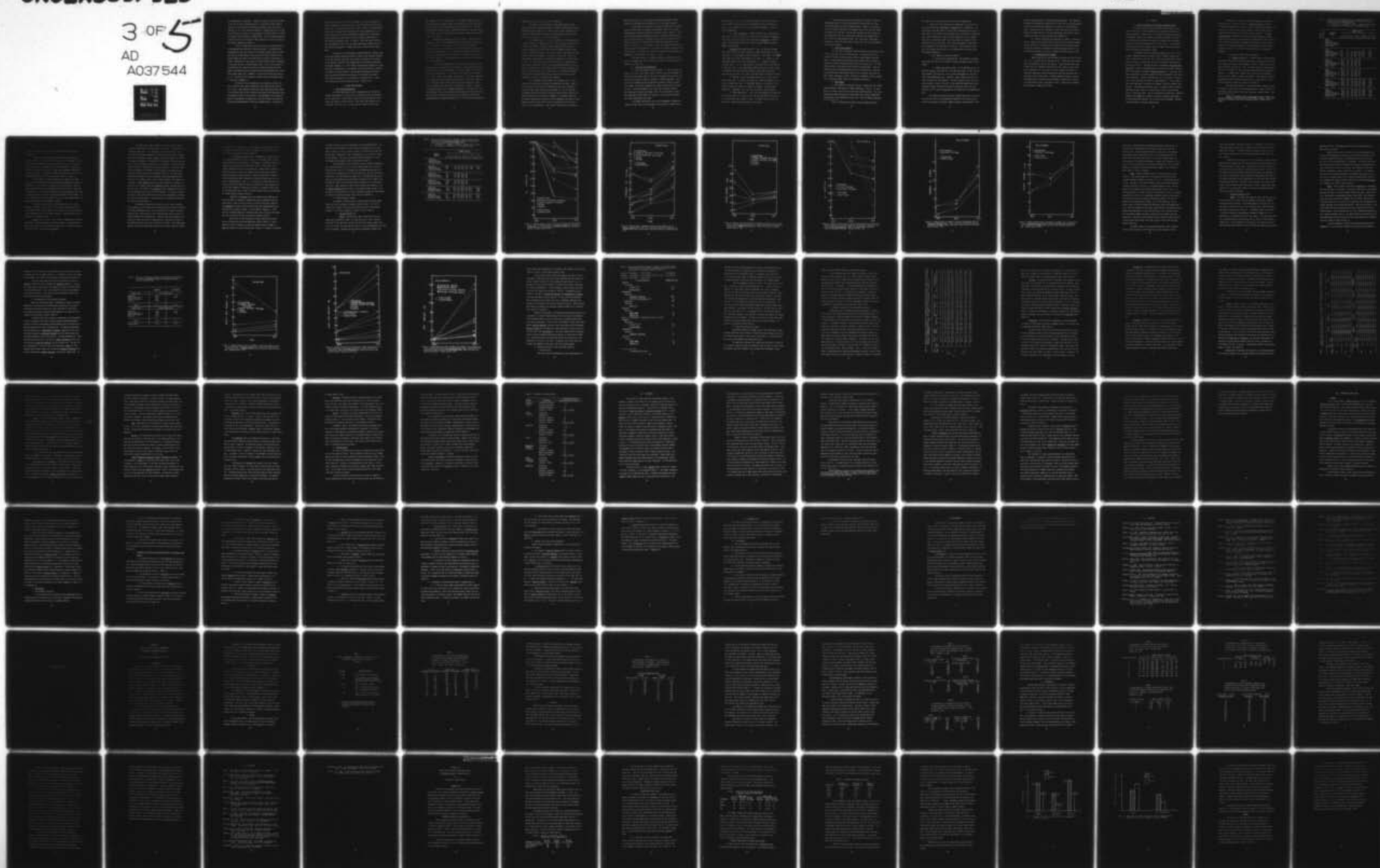

the dredge material depository. Chemical and physical analyses were made in the fall of 1973 of dredge deposits in a drained salt pond (Pond 3) adjacent to the intertidal dredge material deposits where the field experiments of this 1974 study were conducted. Although the sites are somewhat different the origin of the two deposits of dredge material is identical--namely, near the mouth of Alameda Creek. Thus, for present purposes, analytical data on the contents of the substrates of the two sites may afford useful comparisons, (Plate 1).

Little is known about the rate of invasion or rehabilitation of an unpopulated marsh habitat by infaunal organisms. The Alameda Creek dredge material that had occupied the intertidal zone for about two years and that was freshly graded in May just prior to the initiation of the present study, was found to be almost entirely lacking in macroscopic infaunal invertebrates in early June, less than one month after the grading of the marsh surface to achieve proper levels. Thus, it was possible to include within the scope of the study an interesting appraisal of the type of invertebrate invasion taking place during the greater part of the 1974 growing season (May - November) in South San Francisco Bay (Section VI, B). The nature of the invasion of control plots by volunteer plants is indicated in Appendix F.

The scope of the investigation also included an inquiry into certain physical and chemical properties of the plant habitat (Section VI. C and D). Many expected interactions reach toward equilibrium states in the shallow strata of soil adjacent to and nearby the underground stems or rhizomes and roots of marsh plants. Varying degrees of soil porosity permit varying degrees of penetration of the oscillating tidal waters to help aerate oxygen-depleted interstitial sediment waters. They may also

enhance the availability of naturally formed or artificially added nutrients, the absence of which may seriously limit the growth of marsh plants (Tyler, 1971). Since great variation is known to exist in the plant growth of different individual marsh communities of a small geographic area, interest centers on the question of degrees of availability of subsurface plant structures to tidal water and to the nutrients, heavy metals, or other chemical substances conta ied therein. Thus, the scope of the project was extended to fertilize every other experimental growth plot to assess the gross advantage, if indeed such exists, of the nutrient supplement.

The scope of the investigation included additional chemical studies of the oxidation-reduction potential (redox) of the substrate adjacent to and away from the subsurface plant tissues in relation to its bearing on the anaerobic conditions that predominate in the cordgrass subsurface environment (Appendix A). These chemical analyses were extended to include quantitative measurements of ten elements that become directly or indirectly involved in complex metabolic and interacting processes that characterize the physical-chemical environment of an intertidal salt marsh. Cost records have been kept of the materials and effort used as a basis for estimating marsh grass production costs. (Section VI E).

V. METHODS AND PROCEDURES

A. Field Planting Operations

The field experimental area at Alameda Creek was leveled and surveyed by engineers of the Army Corps of Engineers in May in accordance with the plans of Mr. Paul Knutson, biologist and Project Monitor of the Corps' San Francisco District Office. Three levels were formed in the intertidal zone in May 1974. At that time, the levels of the A plots

were intended to be 8 - 9 feet (2.44 - 2.74 m) MLLW. However, the levels of these plots were somewhat higher in May averaging 9.9 feet (3.0 meters) above MLLW when the planting operations took place (Table 1). They settled appreciably during the May - November 1974 period. There were 24 plots 5 to 5 meters in size at the A level and these were planted with pickleweed (Plate 5 and Table 1).

Cordgrass was planted at the B and C levels. The B level plots averaged 8.17 feet (2.49 m) above MLLW, and the C level plots, 6.89 feet (2.10 m) above MLLW. There were 29 B and 29 C test plots planted (Plate 5: Table 1). Due to difficulties in operating heavy equipment for leveling the dredge material in the intertidal zone, there were numerous depressions that created shallow tide pools in a number of the B and C test plots, (Plate 1). A survey was conducted to establish the northwestern corner of each plot.

There were 10 different test conditions with controls for cordgrass and 6 test conditions for pickleweed and in each case one-half were fertilized with a single application of commercial crystalline fertilizer (nitrogen and phosphorus). The 5 types of test conditions for cordgrass were: seeds of robust (tall growth form) plants, rooted nursery seedlings of the robust plant type, rooted nursery cuttings of the robust type and also of the dwarf (short growth form) plants, and transplants of small bunches of adult robust type plants, referred to as "plugs" or "tumps," and measuring about 13 cm in diameter (Appendix H). For each of the ten test conditions (fertilized and unfertilized) there were 5 replicates used making a total of 50 test plots (exclusive of controls), less 2 plots omitted because of improper substrate level. All test plots were chosen at

random in level A, and in levels B and C (Plate 5).

The types of test conditions for pickleweed numbered three: namely, freshly cut, and hence unrooted, cuttings; rooted nursery cuttings; and rooted nursery seedlings. For each of the six test conditions (fertilized and unfertilized) there were 3 replicates making a total of 18 test plots, exclusive of the controls (Appendix H).

The cordgrass seeds, collected in the fall of 1973 and preserved in brackish water at a temperature of about 4°C until May, were tested for viability and planted in concentrations of about one liter per plot. These were raked in to minimize their being dislodged by wave and tidal actions. The rooted cuttings, seedlings and "plugs," were spaced at about 3 meter intervals and numbered, in each case, 25 per plot. The "plugs" were placed in appropriately sized holes and covered with a shallow layer of soil. All the nursery rooted plants were grown in a dredge material-sand mixture in peat pots 10 by 10 cm and transplanted therein at the test area. This proved to be a satisfactory method for growing, handling, and establishing the several types of transplants. In the case of the dwarf rooted cuttings both the fertilized and unfertilized test plots were treated with zinc and iron-conditioning treatment.

For pickleweed, similar numbers of transplants per plot were used and the handling and transplanting methods were the same. Here, the use of peat pots for "heeling in" purposes was particularly beneficial since the higher level substrate that averaged 9.9' (3.0 m) above MLLW in November following considerable subsidence after the May planting, was often relatively firm as indicated in Appendix A. Moisture content of the natural substrate was lower due to less submergence time than the lower intertidal levels of the B and C plots that averaged 8.17' (2.49 m) and 6.89' (2.10 m), respectively. Five liters of the freshly cut shoots were

applied per test plot. In the case of the rooted cuttings and rooted seedlings, 25 specimens were planted per plot at one meter intervals.

As described in more detail in Appendix B, 286 "plugs" of robust and dwarf growth forms of cordgrass were planted in May in 14 transects extending across both the high and low intertidal levels (Table 1). These plantings were designed to measure survival of cordgrass, particularly at the very high and very low intertidal levels, and also to assess the differential capacities for survival of the dwarf and robust forms at the higher and lower levels. The transect "plugs" were spaced at one meter intervals across the intertidal zone, and the rows of the two forms were about 0.5 meter apart. For both forms, two sizes of plugs were used, namely, for large plugs > 13 cm and for small plugs, < 13 cm.

Four seed transects of cordgrass were sown in May and as in the case of the seeded test plots, the seed were raked in to minimize wave and tidal actions (Plate 5).

B. Root and Shoot Measurements

1. Kinds and schedules of measurements. To serve as a base reference, or initial linear growth levels of plant size, ten individuals of each of the four growth forms or individual propagules from each planting stock were selected at random for purposes of linear measurement. Ten of each of the 5 propagules were measured with respect to height of aerial culm, number of stems per propagule, dry weight of shoots and dry weight of roots. Linear measurements of all plantings, including transects were continued in August and October, 1974. Also, the percent survival was determined and the numbers of volunteers in each plot were counted and linear measurements were taken.

Dry weights were made of one surviving propagule, randomly selected, from each test plot and analyzed for dry weight of shoots and dry

weight of roots. Thus, for each growth interval, there were 5 cordgrass plants weighed (5 replicates) and 3 pickleweed plants (3 replicates) of each of the 5 growth forms or types of propagules (Appendix G, Tables 1 - 10, and Appendix H).

2. Linear Measurements. Height of aerial culm is the distance from the soil line to the tip of the tallest leaf in the case of Spartina, and to the tip of the longest stem in the case of Salicornia. Length of shoot is the distance from the soil line to the point where the stem disappears into the leaf.

Salicornia stems were measured if over 2 cm long and included both stems from the root (main stems), and stems branching off the stems (branches). The measurements indicate length of: total stems, i.e., main stem lengths plus branch stem lengths; main stems, i.e., lengths of stems which grew directly from roots; and branches, i.e., lengths of branches from main stems. This last measurement is an average for all the branches on each main stem. It was determined by adding the sum of all the lengths of branches on each main stem and dividing by the number of branches. If a main stem had no stems on it, there is no measurement of branches indicated.

3. Washing. Plants were washed free of soil by spraying with water from a hose. The plants were placed in a sieve and sprayed, washing the dirt through the sieve. In some cases breaking up the clumps of mud with the fingers was required to remove all the mud. The plants were washed until completely free of soil and other debris (mostly algae).

4. Weight Measurements. The samples were measured for length and the plant was then cut to separate the roots from the shoots at the point on the stem where green changed to white. All shoots and roots were then dried with a paper towel and weighed for wet weight.

The roots and shoots were next placed in an oven at 105°C and weighed periodically until the same weight was observed for two consecutive measurements (at least 30 minutes apart). Where it was necessary to dry for longer than one day, the samples were left in the oven, which was turned off, overnight. The oven was turned on the next morning and the samples were left for two more hours after the oven reached 105°C, before the first measurement was made. For large plants, measurements were made to 0.01g, for small plants (usually less than 10 g) measurements were made to 0.0001g).

C. Statistical Procedures

For the linear and weight growth measurements of the several plant forms a 3-way analysis of variance was used. For assessing variation in survival of plants in the test plots, the chi square method proved adequate. A useful tabular presentation of the growth results is given by the means and their respective coefficients* of variation (C.V. = S.D./$\overline{m}$ x 100) set forth in the tables giving survival and growth data. These two statistics are also tabulated where practical for the data on: particle size distribution, invertebrate diversity, soil moisture, alkalinity, organic carbon, phosphate, nitrate, chloride ion, magnesium, calcium, copper, iron, potassium, sodium, lead, zinc, manganese, and mercury.

D. Core Samples

1. Soil samples for chemical analyses. Twenty-four core samples were collected (3 replicates at 2 sample elevations, 7 feet (2.1 m) and 9 feet (2.7 m) MLLW during the May and October sampling periods. These core samples were taken contiguous and incontiguous with actively photosynthesizing plants in the experimental marsh area. The core samples penetrated

*The C.V. expresses the average relative standard deviation.

to a depth of 30 cm and the resulting soil core was homogenized.

Locations of the contiguous core samples were in plots of the A and B levels which were Salicornia and Spartina plots, respectively. The incontiguous cores were taken in the corridor area between plots at the A and B levels. Core samples were collected with a coring device constructed with a polyvinylchloride cylinder that was plugged with a vinyl stopper (Duke, Willis, and Wolfe, 1968). Cores were taken to a depth of 30 cm, pushed out of corer into trays. Cores were then wrapped in aluminum foil and transported to the laboratory for analysis. Upon receipt at laboratory, core samples were anlyzed for soil characteristics and kept under refrigerated conditions.

2. Soil Samples for physical analyses.

a. Particle size determinations. The procedures for determining particle size of soil fractions followed the methods used by Emery (1938).

b. Compressive shear strength. In the beginning it was intended to measure slope stability in the intertidal zone. It was soon realized, however, that stability is not a useful measurement for the essentially flat experimental area. Therefore, shear strength was used as an index of cohesion of the sediments. The shear strength in most intertidal mud substrates is taken as one-half of the unconfined compressive strength. Although the shear strength can be used to calculate "slope stability," stability is not a useful measurement for the essentially flat experimental area.

The unconfined compressive shear strength tests were run on cores 7.6 by 2.9 m, first at the Department of Geology of San Francisco State University (courtesy of Professor Raymond Pestrong), and thereafter at the

Point San Pablo Laboratory of the Marine Research Center. The compressive strength was determined by loading the soil cores with an increasing weight of water and recording the compression of the core in inches (Pestrong, 1965). Because of lack of information in the literature on the redox potential of dredge materials, and its environmental implications, special attention was given to the E_h methods used, (Appendix A).

3. Chemical Procedures for analyzing soil samples. Extracts of the soil samples were made according to Walsh (1970) and standard methods of water analyses were employed for the numerous chemical determinations using atomic absorption spectrometric methods where needed (American Public Health Association, 1973; and Environmental Protection Agency, 1971).

E. Invertebrate Benthic Samples

Benthic grab samples were obtained by marking off a 256 cm^2 area, (16 x 16 x 7.6 (depth cm) and removing the soil. Twenty-four grab samples were collected along with the core samples. Three replicates were taken at each of the two intertidal elevations for the A plots and the B and C plots, elevations 3.0 m, 2.5 and 2.1 m, MLLW, respectively (Table 1). These were undertaken in May and October and were made contiguous and incontiguous with the test plants. Standard methods of washing, sorting, and preserving the collections were followed by identification of most of the macroscopic forms to the species levels. Quantities of organisms are expressed in numbers per m^2 area.

VI. RESULTS

A. Survival and Growth in Intertidal Experimental Area.

An index of the total amount of plant growth produced in unit time on a bare area in the intertidal zone is quite different from the biomass produced in a mature marsh. The latter more closely resembles an environmental climax with a dominance of perennial growth of the established plants and new shoots from subsurface rhizomes more than compensating for the death and decomposition of older plants. So the continuous processes of growth and decay approach a dynamic equilibrium fluctuating with time and environmental change.

To properly assess the potential productivity of a bare area of suitably located intertidal marshland, data are needed to compare the extent of seed survival, when they fall to the soil and germinate in nature, with the extent of survival when the seed are treated in the laboratory and sown artificially. Whereas glasswort or pickleweed, _Salicornia pacifica_ Standl. readily disseminates seed that germinate both under laboratory and field conditions, cordgrass, _Spartina foliosa_ Trin., possesses a well-known low potential for seed dissemination and/or germination under natural field conditions. Strictly comparable data are not available, but pertinent results have accrued from this study (Appendix F). Purer (1942) reports that seedlings of cordgrass are uncommon, the plant spreading vegetatively. The Alameda Creek bottom, about 3 kilometers upstream from the experimental area, contains a relatively pure stand of young cordgrass plants of 1973 seed origin. But this unexpected occurrence was, reportedly, caused by the damming of the mouth of the Creek, trapping fresh water in an area historically brackish, for a 3-month period, September - December 1973 (Paul Knutson, personal communication).

Accordingly for cordgrass, the present vegetation assessment of dredge material is predicated largely on Spartina foliosa transplants of laboratory treated robust seeds, of nursery rooted robust seedlings from such seeds, of robust nursery rooted cuttings, of dwarf nursery rooted cuttings, and transplants of robust adult plants ("plugs"). For Salicornia pacifica, transplants of freshly cut unrooted vegetative shoots, rooted nursery cuttings, and rooted nursery seedlings were used. The findings from these experimental assessments are expected to provide useful guidelines for subsequent commercial planting operations (Tables 2 and 3; Appendix G, Tables 1 - 10). Much of the original data is tabulated in Appendix H.

1. Survival and linear indices of growth.*

a. Spartina foliosa Trin. Survival data for the 5 replicate experimental plots, fertilized and unfertilized, covering the periods from May to August and October, are presented in Table 2. Except for the robust rooted cuttings, survival was > 50%. The robust "plugs" survived the best--83% and 77% in October for fertilized and unfertilized plots, respectively (Table 2). In almost every instance the fertilized plot exhibited the highest survival (based on combined plot means). The differences measured between fertilized and unfertilized plots are, in some instances, considered statistically significant (figure 1 and Table 2).

The relatively high drop in survival from May to August could be attributed to shock incurred during transplantation. Removal of plants to the higher salinity waters of the South Bay may be a causal factor. There

*Numbers of Spartina seeds and Salicornia unrooted cuttings for survival estimates could not be determined at time of sowing. Hence, 100% survival was denoted as the number of plants present in these plots in August.

Table 2. Survival and growth data for the May - October period of the 4 growth forms of S. foliosa planted in fertilized (F) and unfertilized (U) plots in mid-May 1974.
1. % survival; 2. numbers of stems; 3. growth (cm) in height; 4. dry weights (g.) of shoots; 5. dry weight of roots.

Months	Treatment	PLANTING STOCK	GROWTH INDICES 1 $\bar{X}$	1 C.V.	2 $\bar{X}$	2 C.V.	3 $\bar{X}$	3 C.V.	4 $\bar{X}$	4 C.V.	5 $\bar{X}$	5 C.V.
		Seeds										
		Seedlings										
		Rooted Cuttings, R.										
	F	Rooted Cuttings, D.										
5		Robust Plugs										
		Seeds										
		Seedlings	100		1.0	0	8.4	41	0.02		0.02	
		Rooted Cuttings, R.	100		1.3	52	37.9	28	0.93		2.44	
	U	Rooted Cuttings, D.	100		2.1	35	20.3	28	0.28		0.40	
		Robust Plugs	100		5.2	30	55.3	13	6.51		8.78	
		Seeds	100		1.4	17	9.4	23				
		Seedlings	60.8		3.0	54	14.5	32				
		Rooted Cuttings, R.	38.4		1.9	44	16.6	48				
	F	Rooted Cuttings, D.	81.6		3.1	56	15.5	41				
8		Robust Plugs	93.6		4.3	60	21.0	40				
		Seeds	100		1.1	11	9.2	26				
		Seedlings	58.4		2.7	57	13.9	37				
		Rooted Cuttings, R.	25.6		1.7	51	15.2	49				
	U	Rooted Cuttings, D.	64.0		2.4	57	13.8	41				
		Robust Plugs	82.4		4.1	58	23.7	41				
		Seeds	100.3		3.3	53	16.9	26	0.33		0.43	
		Seedlings	52.8		8.0	75	21.8	23	0.90		1.32	
		Rooted Cuttings, R.	35.2		3.7	54	25.5	29	1.06		4.34	
	F	Rooted Cuttings, D.	72.8		5.9	70	18.6	25	1.09		2.34	
10		Robust Plugs	83.2		6.9	73	24.6	22	3.03		20.00	
		Seeds	81.3		1.7	55	17.4	37	0.30		0.37	
		Seedlings	55.2		6.1	62	19.6	29	0.50		0.89	
		Rooted Cuttings, R.	20.8		3.4	54	26.2	21	1.80		7.46	
	U	Rooted Cuttings, D.	66.4		5.3	50	18.0	25	0.87		2.16	
		Robust Plugs	76.8		6.3	54	28.8	22	2.43		15.01	

is also the possibility of some of the smaller plants being removed by waterfowl.

Numerical data on stems (a good growth index) produced by the several different plant forms are given in Table 2. The numbers of shoots were increasingly observable from a distance in the late fall season, but plot variability was expectedly high. While the numbers of stems present scarcely increased during the May - August period remaining from about 2 to 4 per plant unit, by October the number had, except for plugs, more than doubled being greater in the fertilized plots (Plate 1; figure 2).

Data on numbers of stems produced and on growth of the plants in height have been subjected to several statistical treatments to assess the dependability of the indices of growth and the significance of numerical differences obtained for the indicated periods and locations. Coefficient of variation, C.V., expressed as percentage, has been employed as one means of comparing directly the several types of measurements (Woolf, 1968). The C.V., excluding seeds, was from 44% to 75%, but the most common coefficients were between 54% and 60% for numbers of stems.

In August, the artificially (hand) seeded plots had variable numbers of seedlings ranging from 2 to 134, and in October from 5 to 83. In the seed transects, seeds seemed to survive best at levels with lengthy tidal submergence and some atmospheric exposure. Seed germination was not observed in the tidepool areas.

Height, as an index of initial growth, is apparently of secondary importance. Subterranean growth of rhizomes and roots is responsible for more initial activity. But, during the second year, a relatively conspicuous plant cover of cordgrass may be expected.

The height data, given in Table 2, are of particular interest. The May reference data for height are of little value for comparison with subsequent growth data. This, seemingly, is due to die-back of aerial plant parts associated presumably with the shock of transplantation *per se* and, too, environmental change. However, the data for August and October are especially rewarding. The height of the seedlings from hand-sown seed was over 9 cm. in August, and about 17 cm. in October. The fertilized and unfertilized plots yielded similar results (figure 3). In fact, no signi- ficiant differences attributable to fertilization of the plots were ob- tained for any of the growth forms employed (Table 2). Considering the fertilized and unfertilized plots together, transplanted seedlings were about 8.4 cm in height in May, 14 cm in height by August, and around 20 cm by October. Robust *Spartina* cuttings grew from about 16 cm in August, to around 26 cm by October, while dwarf *Spartina* cuttings increased from 15 cm to over 18 cm. The height of the *Spartina* "plugs" averaged 25 cm and 29 cm for the combined fertilized and unfertilized plots. For growth in height, the plants in the unfertilized and fertilized plots displayed no consistent and significant differences. The coefficients of variation usually ranged from about 20 to 42% (Table 2).

Considering the potential variability in the origin, handling, transplantation, soil moisture due to standing water at low tide, and levels of the many experimental plots, the similarities of the means of the mean heights of the 5 replicates for the 5 different plant forms are quite re- vealing (Plates 4 and 5; Appendix G). From the practical standpoint of be- ing able to seed a bare area of dredge material, the growth in height of the seedlings of sown origin are of particular interest. Their August mean heights for fertilized and unfertilized plots are almost identical, namely,

9.4 cm and 9.2 cm, respectively. By late October, they had almost doubled in height and remained almost identical, namely, 16.9 cm and 17.4 cm for fertilized and unfertilized plots (figure 3).

b. Salicornia pacifica Standl. Pickleweed is a dominant plant of the upper littoral zone, but it coexists, at its lower level of intertidal distribution, with cordgrass. This species is a perennial form that inhabits high, relatively dry situations as well as lower levels with greater submergence time and less growth rate. Rooted nursery seedlings, unrooted cuttings or shoots, and rooted nursery cuttings were tested for growth increments based upon number of stems and plant height. Seeds are readily produced and readily germinate in nature and hence, were not subjects of experimentation. Due, it it is believed, to tidal wash of the unrooted cuttings distributed on the soil surface, and to the irregularities in level and firmness of substrate in portions of the upper littoral zone of the experimental area, results for these cuttings tests are not adequate for growth analysis purposes (Table 3).

Regarding the survival tests, the rooted nursery seedlings and rooted cuttings, as expected, yielded highly positive practical results. Consistently, higher survival occurred in the fertilized plots (Table 3). For seedlings, the unfertilized and fertilized plots produced 69% and 80%, respectively, by August, and 64% and 73% by October (figure 4). A 50% survival is deemed adequate for producing cover, but, of course, the higher the survival the more rapidly the cover will develop (Table 3).

Growth tests of the transplanted nursery seedlings and rooted nursery cuttings yield consistent meaningful results (Table 3). Here, in three out of four instances, significantly greater growth in number of stems was obtained in the fertilized plots (figure 5). Die-back so prominent

in cordgrass plants was not so conspicuous in the pickleweed plants. The seedlings grew from about 1.4 stems (a mean of the means of the 3 replicates) in May to 4.4 and 7.2 stems by August in the unfertilized and fertilized plots, respectively, and, correspondingly, to 17.3 and 27.7 stems by late October. The stems of the rooted cuttings numbered 6.2 in May and reached a mean number of about 22 by October (Table 3).

The mean height of the transplants in May at time of transplantation from the nursery was 11.1 cm for the seedlings and 20.3 cm for the rooted cuttings (Table 3). By August, the corresponding means were 14.7 cm and 18.2 cm, respectively, for unfertilized plots, and 17.4 cm and 20.3, respectively, for fertilized plots (figure 6). The seedlings grew continuously, but with greater vigor from August to October, in all about 14 cm, from May to October in the intertidal plots and about 21 cm in the fertilized plots. Here, apparently, fertilization proved to be effective. For the rooted cuttings growth was mainly in the August-October period. Loss of plants in fertilized plot 1 of the 3 replicates accounts for the low mean of the means for these particular tests (Table 6; Appendix G).

2. Weight indices of growth.

Dry weights of shoots and roots were measured to provide added indices of size and growth of cordgrass (Tables 2 and 3). As for the linear growth studies, fertilized and unfertilized plots were examined (figures 7 - 9; Plate 3; Appendix G, Tables 7 and 8, 9 and 10).

a. Spartina foliosa Trin.

Shoots. When planted in May, the shoots of the robust plugs were the heaviest, namely, 6.5 grams and the C.V. was 75 percent. The shoots of the remaining 4 growth forms were much lighter ranging from 0.02 g. to 0.93 g. for seedlings and the C.V.'s were correspondingly low--from 0.3 to 21 percent. Although only one plant was selected at random from

Table 3. Survival and growth data for the May - October period of the 3 growth forms of Salicornia pacifica planted in fertilized (F) and unfertilized (U) plots in mid-May 1974.
1. % survival; 2. numbers of stems; 3. growth (cm) in height; 4. dry weight (g.) of shoots; 5. dry weight of roots.

		PLANTING STOCK	GROWTH INDICES 1 $\overline{X}$	1 C.V.	2 $\overline{X}$	2 C.V.	3 $\overline{X}$	3 C.V.	4 $\overline{X}$	4 C.V.	5 $\overline{X}$	5 C.V.
5	F	Seedlings										
	F	Rooted Cuttings										
	F	Unrooted Cuttings										
	U	Seedlings	100		1.4	50	11.1	32	0.26		0.10	
	U	Rooted Cuttings	100		6.2	50	20.3	33	0.81		0.30	
	U	Unrooted Cuttings	-		-	-	-	-				
8	F	Seedlings	80		7.2	82	17.4	44				
	F	Rooted Cuttings	92		9.2	68	20.3	36				
	F	Unrooted Cuttings	100		3.4	46	8.9	34				
	U	Seedlings	69.3		4.4	69	14.7	35				
	U	Rooted Cuttings	57.3		7.5	53	18.2	46				
	U	Unrooted Cuttings	100		4.0	0	13.8	0				
10	F	Seedlings	73.3		27.7	87	32.0	34	30.2		2.65	
	F	Rooted Cuttings	61.3		22.1	53	18.9	24	27.4		4.76	
	F	Unrooted Cuttings	12.5		5.4	27	11.3	9	4.3		1.08	
	U	Seedlings	64		17.3	85	25.5	42	11.0		2.52	
	U	Rooted Cuttings	48		23.1	67	27.4	28	9.7		1.86	
	U	Unrooted Cuttings	33.3		10	0	19.2	0	11.1		1.72	

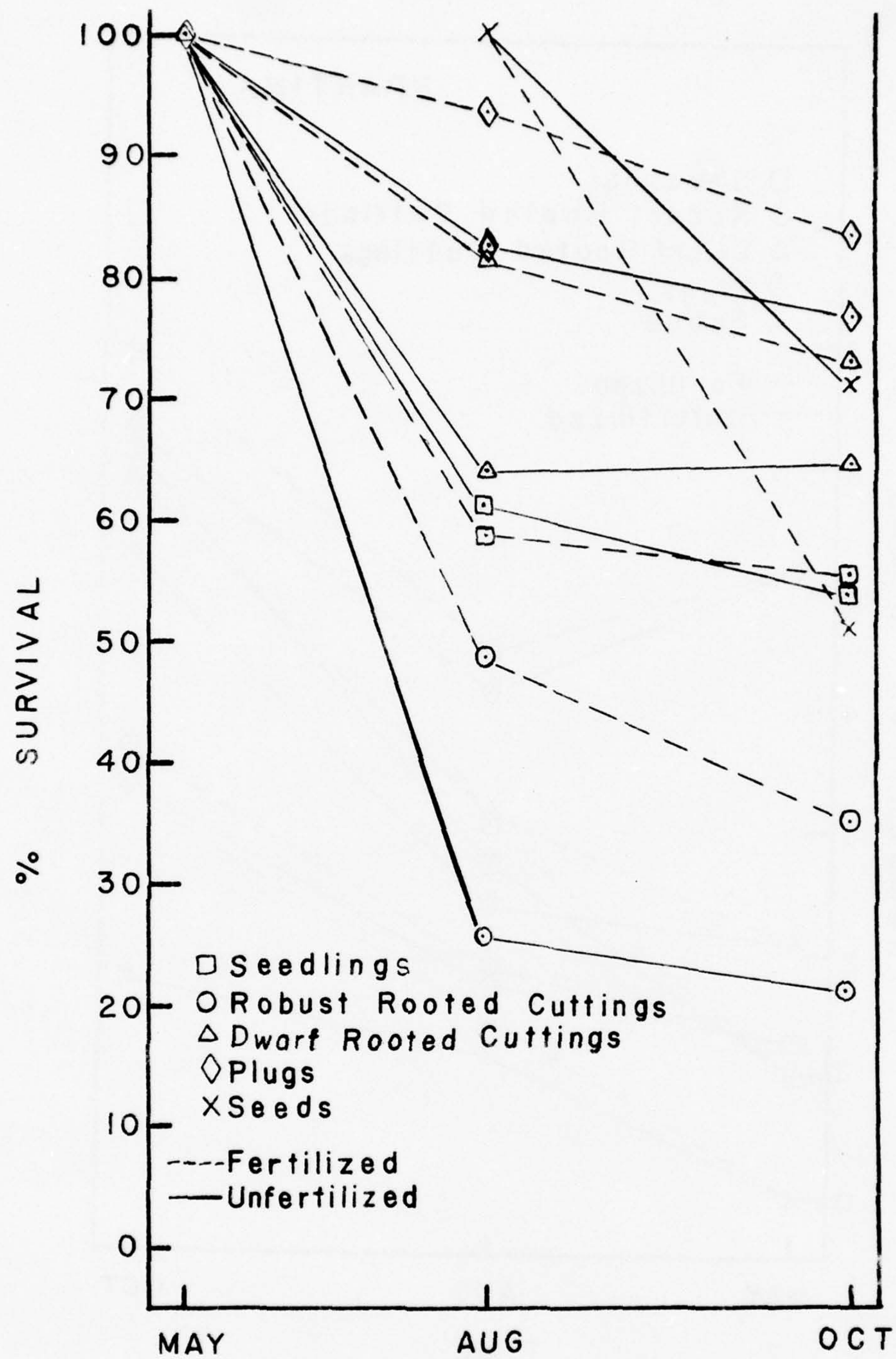

Figure 1. Showing percent survival of five fertilized and unfertilized growth forms or "starter types" of Spartina foliosa Trin. planted in experimental plots at Alameda Creek, South San Francisco Bay during the May - October period, 1974.

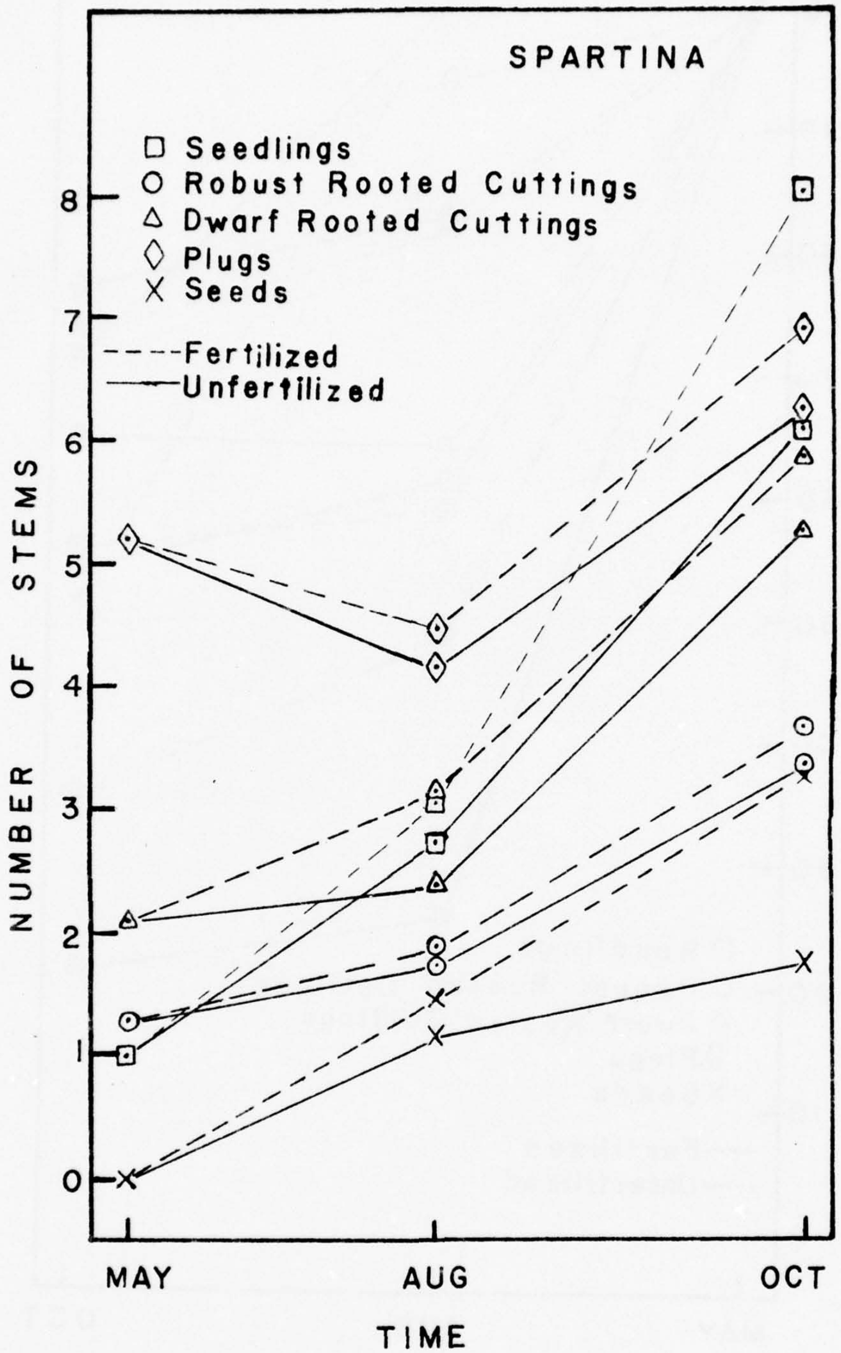

Figure 2. Showing growth in number of stems of five growth forms of Spartina foliosa Trin. under fertilized and unfertilized conditions at Alameda Creek, South San Francisco Bay during the May - October period, 1974.

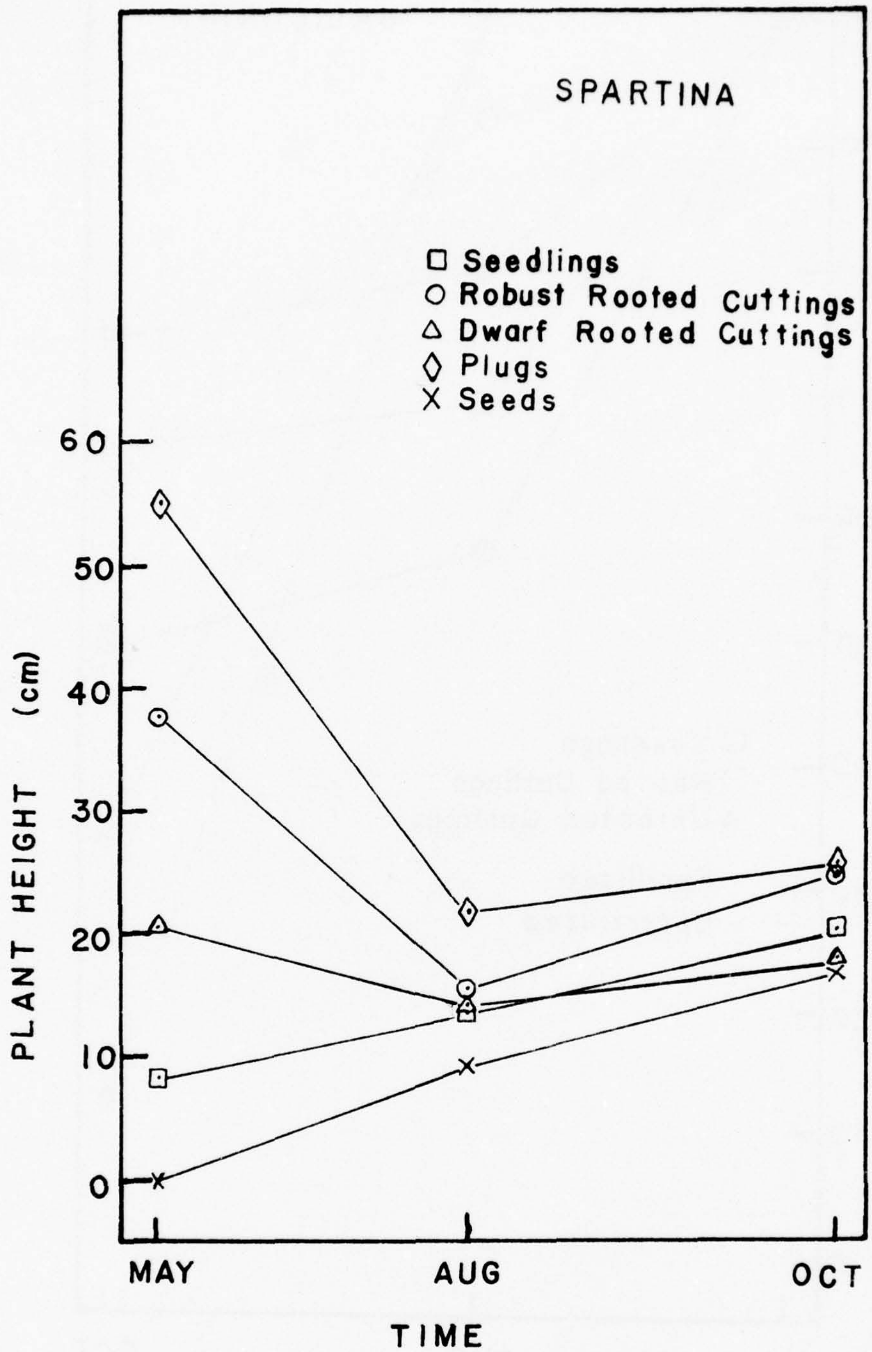

Figure 3. Showing the absolute growth increments of height in cm. of five growth forms of Spartina foliosa Trin. under fertilized and unfertilized conditions at Alameda Creek, South San Francisco Bay during the May - October period, 1974.

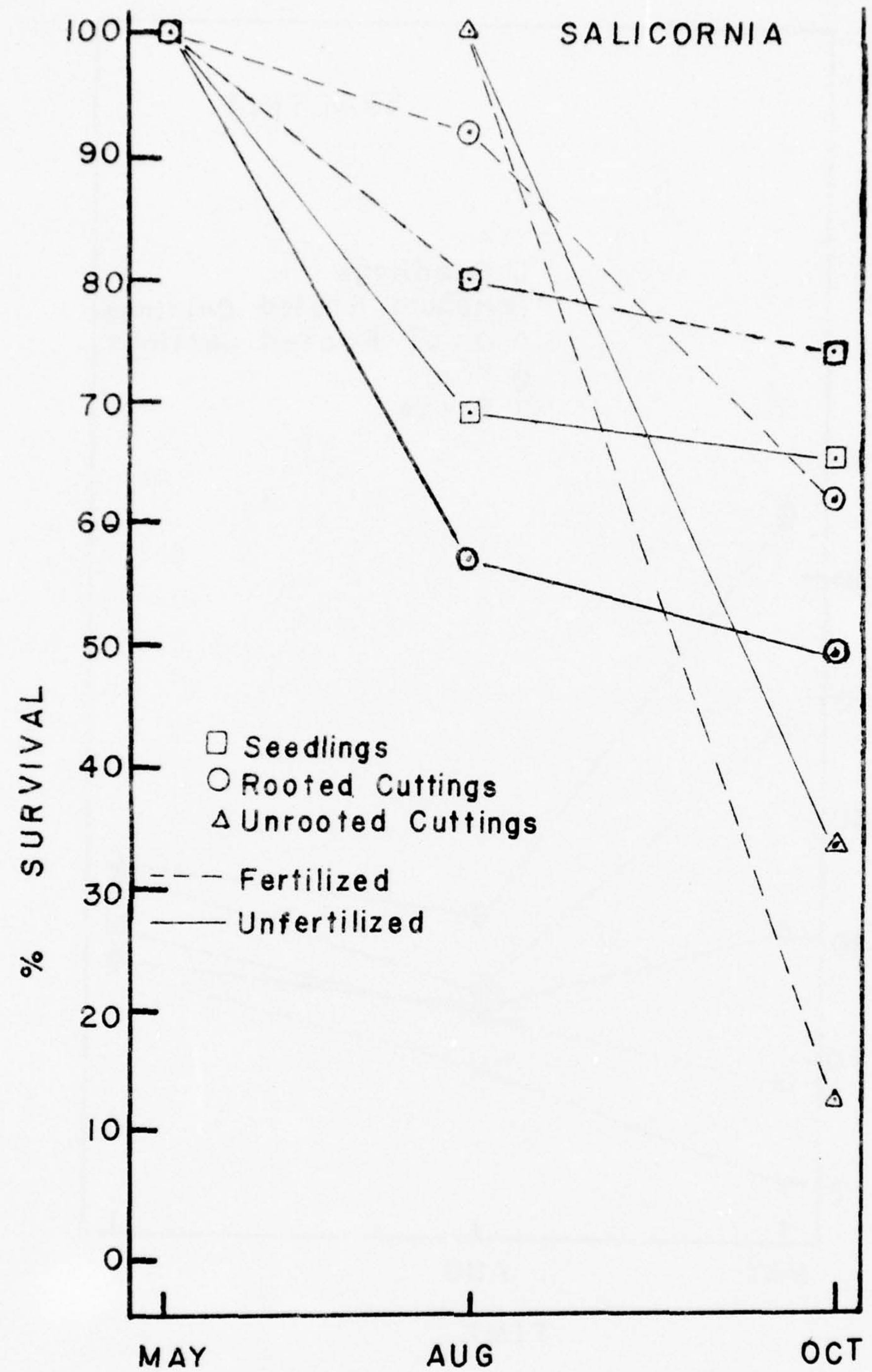

Figure 4. Showing percent survival of fertilized and unfertilized nursery rooted seedlings and cuttings, together with unrooted, vegetative cuttings of Salicornia pacifica Standl. at Alameda Creek, South San Francisco Bay during the May - October period, 1974.

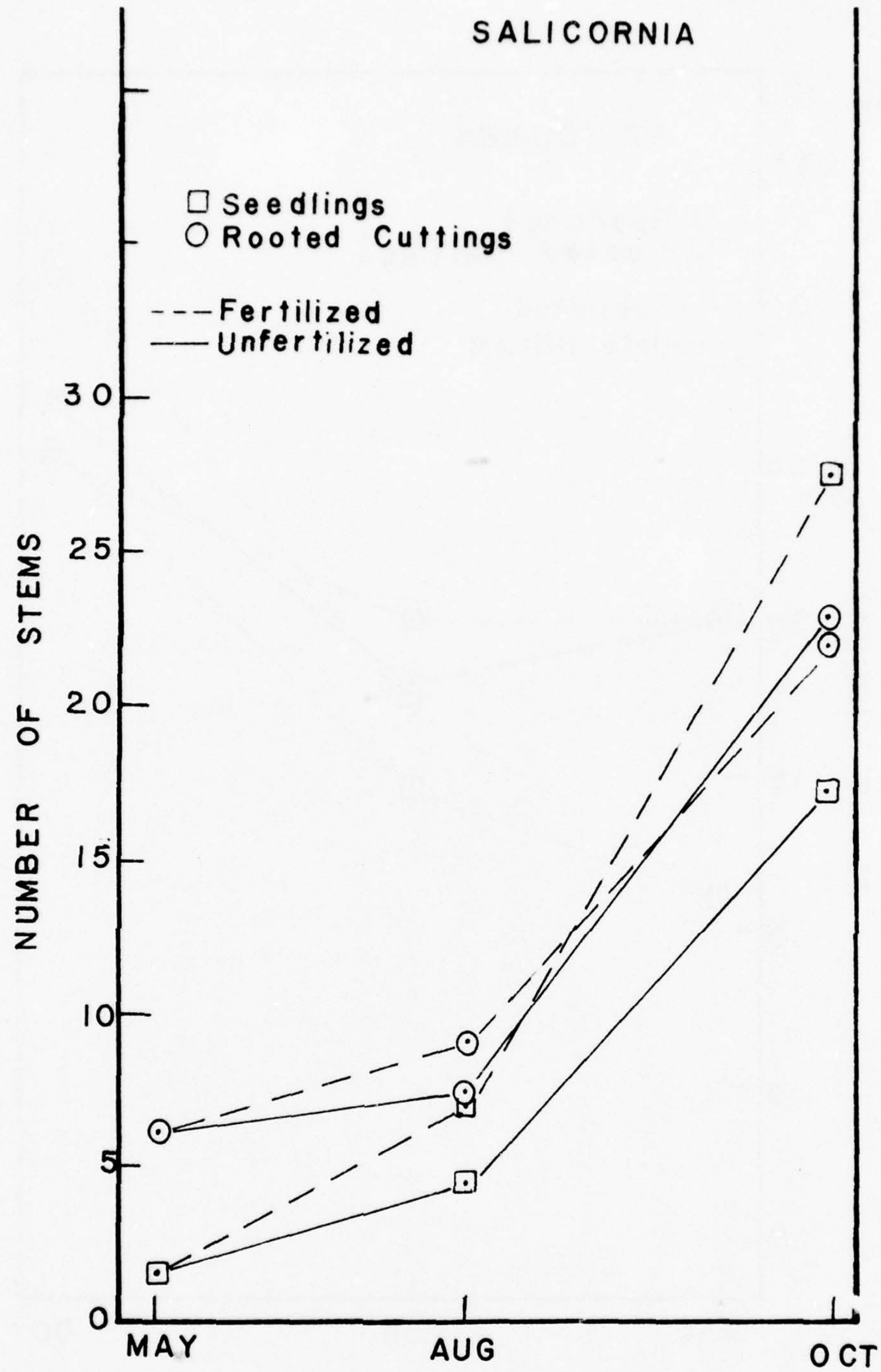

Figure 5. Showing growth in number of stems of three growth forms of Salicornia pacifica Standl. under fertilized and unfertilized plot conditions at Alameda Creek, South San Francisco Bay during the May - October period, 1974.

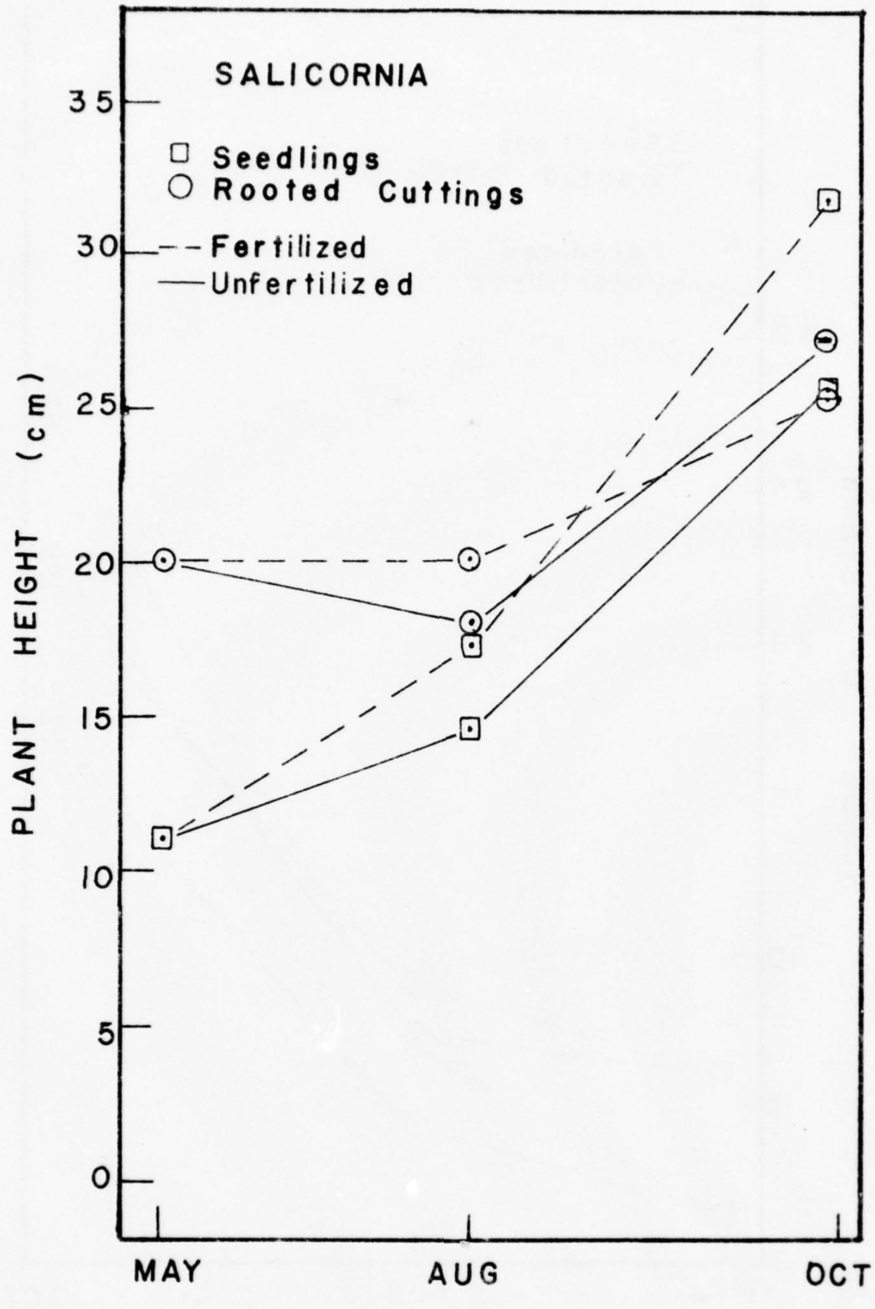

Figure 6. Showing absolute growth increments of height in cm. of two growth forms of Salicornia pacifica Standl. under fertilized and unfertilized plot conditions at Alameda Creek, South San Francisco Bay during the May - October period, 1974.

each of the 5 replicate plots for weight measurements, the data are considered fairly representative of major growth trends during the May - October period. The only positive change in weight was in the seedling shoot growth--namely, from 0.02 to 0.9 g., or a percentage addition of 4350 in the fertilized plots (Table 2). The others remained about the same except for the plugs that decreased in weight due, presumably, to die-back as a result of the shock of the transplant operation. But, with one exception, the growth in shoot dry weight was highest in the fertilized plots (Table 2, figure 7, Plage 3).

Roots. Root dry weights present a far more positive picture (Table 3). The absolute mean gain in dry weight of robust plugs (fertilized) from May to October, was about 12 g., i.e., a percentage addition of 128. The roots of the rooted cuttings of fertilized robust cordgrass increased from 2.4 g. to 4.34 g., a percentage addition of 80%. But the growth of the seedlings was the most notable--from 0.02 to 1.32 g., i.e., an absolute growth increment of the fertilized plants of 1.30 g. or a percentage addition of 6500. This percentage increment, being the truest measure of growth activity, may be used for comparative purposes. The root dry weights of the seedlings were highest in the fertilized plots--1.32 g. versus 0.89 g. in absolute growth and 6500 versus 5000 in percentage addition. With the exception of the robust rooted cuttings, the remaining three growth forms grew better in the fertilized plots, e.g., the robust plugs grew 128 percent compared to about 70 percent in the unfertilized plots (figure 8). The roots of dwarf cuttings like the shoots of dwarf cuttings failed to grow significantly--less than 2 grams--in both fertilized and unfertilized plots.

The aerial shoots of all growth forms gained little in weight. In fact, the dry weights of the robust plug shoots decreased in both

fertilized and unfertilized plots (Table 2). Contrariwise, the roots of these plugs gained significantly in weight as did the roots of the other growth forms (Table2). The dwarf plugs that showed no shoot growth produced minimal root growth in the fertilized and unfertilized plots (figures 7 and 8).

Despite the low values of n, it is of interest to compare percentagewise the root weights with the sum of the root and shoot weights for the four growth forms or starter types. The means of the ratios for the fertilized and unfertilized plants are about the same, namely, 73.7% and 75.5%. The seedlings and dwarf rooted cuttings had the lowest root percentage in both cases, and the robust rooted cuttings and robust plugs had the highest, namely, about 80% and 86%, respectively, for the fertilized and unfertilized plants (Table 4). The mean of the ratios for all the four growth forms of fertilized and unfertilized plants is 74.5%. Hence, about three quarters of the plant weight resides in the root system and one-quarter in the aerial portion of the plant.

b. Salicornia pacifica *Standl.*

Shoots. Dry weights were taken of shoots and roots arising from the freshly cut planted cuttings (vegetative cuttings), rooted cuttings and nursery seedlings. The unrooted vegetative cuttings with only one exception failed to survive in all replicate plots, but the remaining two growth forms grew well (Table 3). The seedling shoots in the unfertilized plots produced a mean absolute increment of growth of 10.7 g., equivalent to a percentage addition of over 4,000. In the fertilized plots, the corresponding growth increases were 30.0 g. and over 11,000 percent, respectively. Like the seedlings, the growth of the rooted cuttings was high and significantly greater in the fertilized plots where the percentage

addition was nearly 5,000 compaed with 1100 for the unfertilized plot, shoot weights, (Plage 3).

Despite the fact that the freshly cut, planted, vegetative cuttings of the pickleweed only took hold in one of the six replicates, fertilized and unfertilized plots, the significance of this one survival, which was in the unfertilized plot, is important. This type of planting, involving simply the surface distribution and raking in of vegetative cuttings, should prove to be far less costly, on a commercial scale, then heeling-in transplants rooted in peat pots in a nursery. It is notable that the cuttings rooted independently and produced shoots comprising 30 stems with an average weight of 33 g. during the 5-month period (Table 3). This represents the highest number of stems for any individual Salicornia plot, (Appendix G), Tables 5 and 9; figure 5).

Roots. The dry weight of the roots of Salicornia is, expectedly, much less than that of the shoots. The growth of the roots of the seedlings was about the same in the fertilized and unfertilized plots, namely, about 2.6 g. representing a percentage addition of about 2500. The rooted cuttings grew more, the absolute increments for the unfertilized and fertilized plots being 1.56 g. and 6.85 g., respectively, the corresponding percentage additions being 520 and 2283 percent. There was no survival in one of the three fertilized seedling plots and one of fertilized plots with rooted cuttings. The root weight was 5.15 g. for vegetative cuttings that had a shoot dry weight of 33.3 g. The data are from the unfertilized plot that represented the single survivor of the 6 plots planted with vegetative cuttings, (Table 3; figure 9; Plate 3).

From the standpoint of stabilizing fresh dredge material with vegetation, it is of practical interest to note that root dry weight of

cordgrass is 3 or 4 times that of the shoots at this early and vital stage of growth cover of the dredge substrate. In comparison, the dry root weight of pickleweed is only about 10 to 25 percent of the shoot weight (Table 4).

Thus, for ready comparison with the distribution of weight in Spartina, similar ratios are presented for Salicornia (Table 4). The percent root weight in seedlings was 8% compared to 14.8% for rooted cuttings in the fertilized plots. But, in the unfertilized plots, the percentage root weight was similar. The overall average root weight is seen to be only 14.3% of the total plant weight.

B. Invertebrates of the Intertidal Substrate

Among the informational gaps in knowledge of infaunal intertidal populations is the qualitative and quantitative character of the biotic succession following the exposure of a bare substrate to tidal waters. This study has provided an unusually good opportunity to study the first stage of the successional pattern, (Table 5).

An idea of what forms to expect as inhabitants of the experimental area is provided by the benthic samples taken by the Marine Research Center in 1973 at an undisturbed intertidal mudflat and a tidal gully of a marsh located one mile south of Alameda Creek. The dominant polychaetous annelids reported are: Heteromastus filiformis, numbering as high as 441 per meter square area; Streblospio benedicti, 333 per meter square area; and smaller numbers of three other species. Ostracods numbered 258. There were 806 bivalve molluscs of the species, Macoma inconspicua and 43 snails of the species, Nassarius obsoletus, per meter square area. The most common invertebrates in the tidal gully were Cheliferans, Tenais sp. that numbered 516 per meter square area, and molluscs-Nassarius obsoletus, 430 and the ribbed mussel, Modiolus demissus, 118 per meter square area. Six

Table 4. Ratios of Dry Weights of Roots to Roots plus Shoots Expressed in Percent for *Spartina foliosa* and *Salicornia pacifica* of South San Francisco Bay.

	Spartina	Salicornia
Growth Form	**Fertilized Plots**	
Seedlings	59.4	8.0
Rooted Cuttings, R.	80.3	14.8
Rooted Cuttings, D.	68.2	
Plugs, D	86.8	
Mean %	73.7	11.4
Growth Form	**Unfertilized Plots**	
Seedlings	64.0	18.6
Rooted Cuttings, R.	80.5	16.0
Rooted Cuttings, D.	71.2	
Plugs, R	86.2	
Mean %	75.5	17.3
Overall Mean %	74.5	14.3

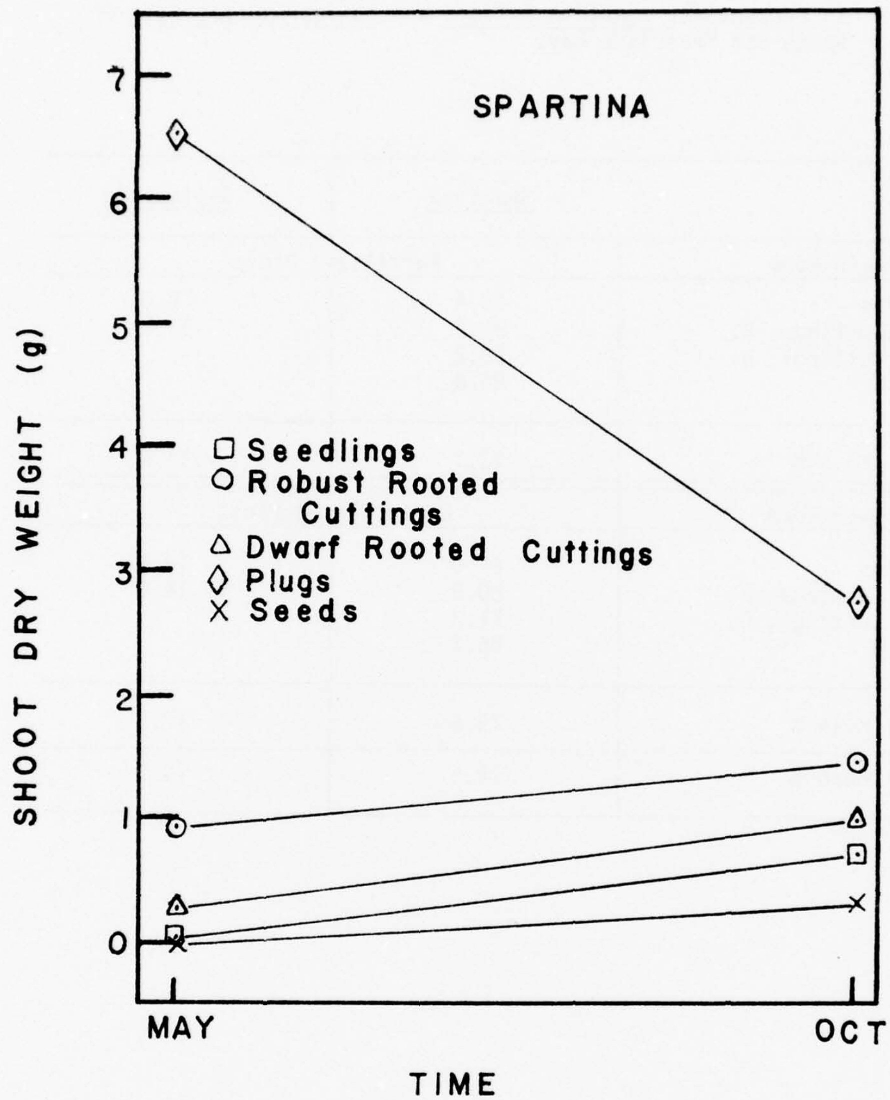

Figure 7. Showing absolute growth increments of shoot dry weight in g. of five growth forms of *Spartina foliosa* Trin. under fertilized and unfertilized conditions at Alameda Creek, South San Francisco Bay during the May - October period, 1974.

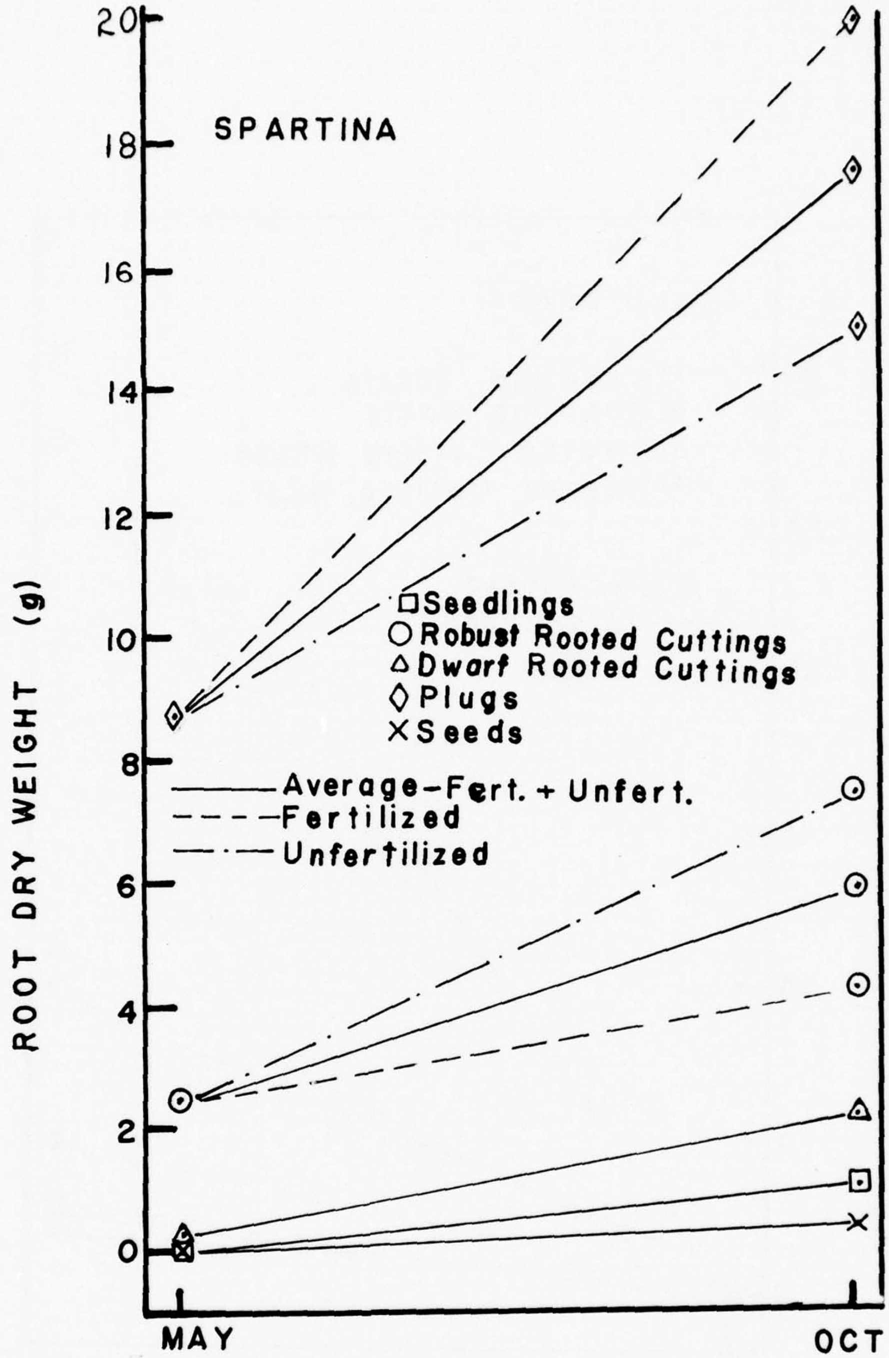

Figure 8. Showing absolute growth increments of root dry weight in g. of five growth forms of Spartina foliosa Trin. under fertilized and unfertilized conditions at Alameda Creek, South San Francisco Bay during the May - October period, 1974.

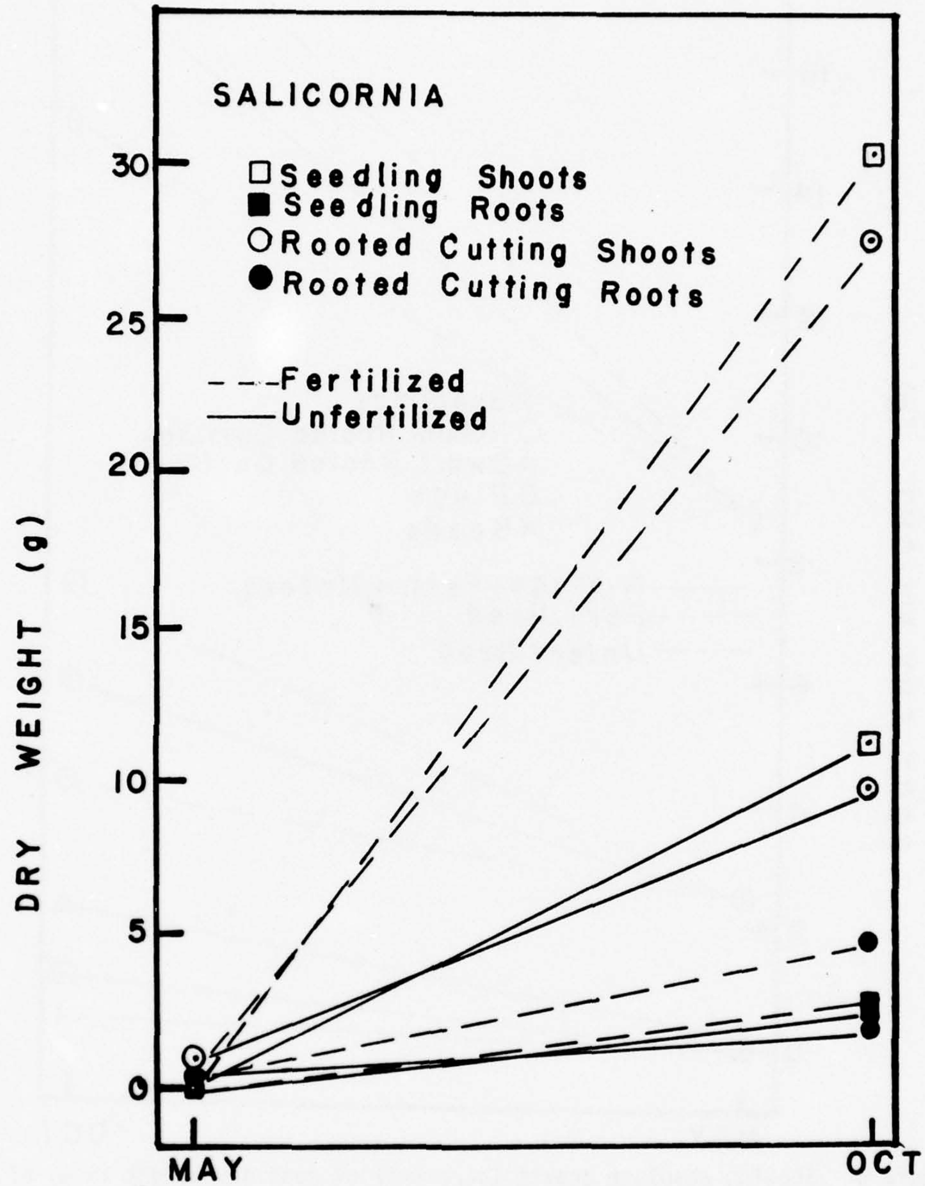

Figure 9. Showing absolute growth increments dry weight in g. of shoots and roots of two growth forms of Salicornia pacifica Standl. under fertilized and unfertilized plot conditions at Alameda Creek, South San Francisco Bay during the May - October period, 1974.

other bivalves were reported but in relatively small numbers and three polychaetes, likewise in small numbers (Mason, 1973).

In the present study, quantitative samples were taken in early June about a month after the level of the intertidal zone was lowered, exposing a barren littoral shore that became the experimental area. Expectedly, the June samples revealed a virtually bare habitat unpopulated by infaunal invertebrates. In early November, benthic samples were again taken and the findings are recorded in (Table 5). Unexpectedly, polychaetes of the species *Streblospio benedicti* and *Hetoromastus filiformis*, the normal dominants, were not sampled. In fact, only two polychaetes were collected and their numbers were low. Expectedly, amphipods were present, in fact they are the dominant invaders (Table 5). Where organisms were found to be present, the replicate samples yielded fairly consistent total numbers of organisms.

Doubtless large numbers of oligochaetes have invaded the area but an approach to a normal infaunal population of macroscopic invertebrates is not expected before the fall of 1975, when a conspicuous marsh plant flora may have developed. Certain local invertebrates, notably the ribbed mussel, *Modiolus demissus*, that are closely associated with the cordgrass, *Spartina foliosa*, may be expected to constitute early arrivals along with the soft shell clam, *Mya arenaria* L. But these numbers exhibit pronounced annual variations depending upon the suitability of conditions for spawning. Their absence does not necessarily reflect the suitability of the substrate for survival of the spat. In general, the results show fewer invaders than expected at the end of the first growing season.

C. Physical conditions of the intertidal substrate

1. Particle size

The size of the soil particulates in the dredge material is

Table 5. Benthic invertebrates present in October grab samples taken at the Alameda Creek experimental intertidal area at the Plot A level and the Plot B level (Plate 5, Table 1).

Location: Contiguous Plot 47:75A — No organisms

Location: Incontiguous - Plot between 47:50A - 47:75A — No organisms

Location: Contiguous - Plot 47:75B

List of Organisms	Numbers/m^2 area
ANNELIDA	
Polychaeta	
Unidentified[1)]	312
Eteone lightii	156
ARTHROPODA	
Amphipoda	
Corophium insidiosum	2266
Corophidae (*Ericthonius*) sp ?	39
Gammaridae	236
Chelifera	
Tanais spp.	156
MOLLUSCA	
Bivalvia	
Gemma gemma	39
Macoma irus	78

Location: Incontiguous - between Plots 47:50 - 57:75B

ANNELIDA	
Polychaeta	
Unidentified[1)]	117
Eteone lightii	39
ARTHROPODA	
Amphipoda	
Corophium insidiosum	117
MOLLUSCA	
Bivalvia	
Gemma gemma	39
Macoma irus	39

[1)] Unidentifiable pieces

related to the water-holding capacity of the soil, to the availability of the organic material to organisms, and to the extent of penetration of surface waters to plant rhizomes that, in cordgrass, are at about 13.5 cm in the mud (Purer, 1936). A mechanical analysis of the soil providing an understanding of the particle size distribution is therefore needed.

The size categories used are > 0.5 mm, > 32 microns and < 0.5 mm, and < 32 microns. Mineral colloidal particles are < 1 micron, the clay fraction is rarely above 2 microns (0.002 mm). By U.S.D.A. standards, clay soil has 48% percent clay particles which are below 0.002 mm in diameter and 28.0 silt particles that range from 0.05 to 0.002 mm. Thus, the silt clay fraction ranges below 0.05 mm and comprises 76.5 percent of the clay soil. It constitutes 60.3 percent of loam soil by definition. The silt-clay fraction of the Alameda Creek dredge spoil usually exceeds 90 percent (Table 6). The range of particles that are > 32 microns and less than 0.5 mm is only about 3 to 17. An average of 91% of the particles were in the > 32 micron category. Less than about 3 percent were found to be greater than about 0.5 mm in diameter. As shown by the low C.V. values, below about 5 percent, the size of the smallest particle size fraction, namely, < 32 microns is relatively uniform (Table 6).

2. Substrate compressive strength.

Unconfined compressive strength in moist intertidal mud is taken as about double the shear strength. Although the shear strength can be used to calculate slope stability, the latter is not useful in a relatively flat zone, such as the Alameda Creek experimental area.

The compressive strength test samples were obtained as 1 meter by 3.5 cm cores of mud, and taken in quadrats of plots at the A, B, and C levels. As expected, the shear strength of the sediment cores decreased in cores

taken closer to the Creek, namely, in B and C level plots.

Little difference was found between cores taken in the A plots which are at the uppermost level, i.e., about 9 feet (3.0 meters) above MLLW and the control cores taken from an unplanted area at the upper level. The compressive strength values obtained were from 350 to 442 pounds per cubic foot (5.6 - 7.1 kg/dm^3). The values determined for the middle of the Plot B zone and the upper part of the Plot C zone, namely, 214 and 126 pounds per cubic foot (3.4 - 2.0 kg/dm^3) may be expected to increase as stands of cordgrass become more abundant on the marsh (Pestrong, 1965). According to Professor Pestrong, regression analysis has demonstrated that moisture content is the most significant independent variable for analysis of sediments from San Francisco Bay (Pestrong, 1965, p. 76).

D. Chemical conditions of the intertidal substrate

Numerous physical and chemical analyses were made of the upper 30 cm layer of the dredge material substrate of the experimental area. The plots were sampled in May and October 1974 to provide a general assessment of the suitability of the environment for survival and growth of biotic communities. Environmental changes in the substrate during the 5-month aging process are likewise of ecological importance. Hargrave (1972), Hutchinson (1957) and others point out that the physical characteristics of the muds that are of sedimentary origin and impregnated with detritus remains and other sources of organic substance are closely interrelated with the bacterial populations and the chemical components. For each of the two intertidal elevations, 3 replicate samples were taken contiguous with test plantings and three were incontiguous, making a total of 12 samples for each of the two sampling periods - May and October. Thus, in view of the limited number of samplings and the inherent environmental variables of such a chemically complex habitat, too long neglected in estuarine studies, the treatment

Table 6. Materials present in substrate of the Alameda Creek experimental area contiguous (C) and incontiguous (I) to *Spartina* transplants. Total organic carbon in % wet weight; alkalinity, chloride ion nitrate N, and phosphate P. in ppm., $\overline{X}$ = means; C.V. = coefficient of variation in %.

	Elev. in feet	Condition	Moisture % $\overline{X}$	Moisture % C.V.	Organic Carbon $\overline{X}$	Organic Carbon C.V.	Alkalinity $\overline{X}$	Alkalinity C.V.	Chloride ion $\overline{X}$	Chloride ion C.V.	Phosphate P $\overline{X}$	Phosphate P C.V.	Nitrate N $\overline{X}$	Nitrate N C.V.	Particle Size % <32 u $\overline{X}$	<32 u C.V.	>32<0.5mm $\overline{X}$	>32<0.5mm C.V.	>0.5mm $\overline{X}$	>0.5mm C.V.
MAY	7'	C	52.2	1.4	11.3	11.7	93.3	6.5	1.00	25.0	116.3	25.1	<5.7	97.2	93.6	0.7	4.2	8.4	2.2	12.9
		I	54.4	4.2	16.6	29.5	146.7	28.9	1.57	11.5	54.9	97.8	<2.3	24.9	85.9	5.2	11.1	41.1	3.0	7.6
	9'	C	45.4	5.5	11.7	9.9	32.0	173.2	1.54	11.7	131.7	58.9	<2.7	43.4	93.4	7.8	6.1	82.5	0.5	52.9
		I	46.0	8.0	15.5	30.0	137.3	9.4	2.01	32.3	87.0	14.4	<5.0	72.2	90.2	3.4	8.0	40.1	1.8	7.1
OCT	7'	C	52.7	5.1	6.1	125.6	108.0	19.6	1.51	27.1	36.3	16.6	7.3	7.9	93.9	0.7	4.5	12.5	1.6	28.1
		I	53.2	5.1	7.6	68.6	94.7	10.6	1.51	11.9	85.3	16.0	6.3	18.3	93.5	3.5	3.3	33.0	3.1	73.7
	9'	C	45.8	3.8	5.4	19.7	110.7	13.6	1.42	22.5	76.7	42.5	5.7	26.8	92.4	3.4	4.8	31.2	2.9	133.2
		I	43.7	4.6	8.3	30.0	100.0	8.0	1.09	20.2	<8.0	0.0	2.3	24.9	82.8	2.0	17.1	10.2	0.15	93.3

here will be largely limited to tabular presentations. Such data will perhaps dispel a number of uncertainties of a practical nature on the favorability of dredge material for producing plant cover, (Tables 6 and 7).

Moisture. The moisture levels in the upper 30 cm sediments varied from about 43 to 53 percent for all locations and times of sampling. Such high levels and variations are expected due to variations in the length of submergence times before sampling at a particular level. The upper littoral zone, A plots, was exposed the longest and hence the moisture content was about 8 percent below that of the lower littoral in May and October. Moisture content is a dominant factor of the habitat, affecting the biochemical interactions and the survival and growth of organisms. So it is interesting to note that Pestrong (1965) who studied marshes in South San Francisco Bay, as well as other locations in the Bay, reports for pickleweed, *Salicornia*, marshes, a range of 82-130 percent. At Dumbarton Bridge Point near Alameda Creek, he obtained a moisture content of 127 percent for *Salicornia* marsh (Table 6).

Alkalinity. Total alkalinity, expressed as calcium carbonate, is subject to high annual variations in Alameda Creek, as is salinity, due to downstream fresh water flows (Table 6).

For May, at the 7-foot (2.1 m) level, the alkalinity was 93 ppm in the contiguous location, and the replicates quite similar as indicated by the coefficient of variation being 6.5%. The alkalinity was 147 ppm in the incontiguous location, the C.V. being 29%. The other levels, shown in Table 6, are likewise not exceptional, except the 32 ppm level for the contiguous location at 9 feet (2.7 m) above MLLW in May. Zero values were obtained for two of the replicates representing a local acid condition and 96 ppm for the third, hence, the high C.V. value of 173%. In general, the variations reported are to be expected in such an estuarine situation.

Chloride Ion. The determinations of chloride ion (Cl^-) or chlorinity of sea water is perhaps the most frequently measured chemical property of seawater, although salinity is the better known designation. Salinity equals 0.03 + 1.805 chlorinity. The chloride content of South San Francisco Bay waters is relatively low in the winter rainy season, but high in summer, due to evaporation, when it may approach the near ocean levels of the Central Bay. Expectedly, then, waters at the mouth of Alameda Creek are subject to marked seasonal variations and such variation is to be reflected in the interstitial surface sediment waters of the substrate of the intertidal experimental area. The C.V. expressing the average relative standard deviation (RSD) is fairly consistent throughout and no obviously significant variations exist between levels or seasons. It should again be pointed out that there are a number of tide pools, albeit shallow, in the experimental area. Their long or short exposure to evaporation in summer and apparent seepage to the surrounding substrate is an inherent chlorinity variable. The records obtained vary from 0.7 to 2.7 ppm.

Phosphate. Phosphorus is one of the most important nutrient elements in tidal waters and is also important in interstitial waters. Valiela and Teal (1974) refer to nutrients as being the most likely factor determining plant growth in a salt marsh. But they are probably not limiting since metabolic processes are operating constantly in the low oxygen levels of the substrate to store such elements, and according to Tyler (1971), most of them are probably sequestered from the tidal waters and not likely to be washed out. It may be that the nutrients are stored at depths not readily available to the marsh plant roots, i.e., below about 8 inches from the surface of the mud. Valiela and Teal (1974) analyzed their

core samples in relation to depth and found dead matter predominantly below the depth of occurrence of the rhizomes and roots. They report significant increases in the nutrient levels of sediment water in marshes treated with phosphates and nitrates. However, their preliminary results suggest no positive growth response by the roots and rhizomes. That the added nutrients do, however, become available to the underground plant structures is significant to the present study.

The May data for the two Alameda Creek levels appear comparable, but there is a notable difference between the contiguous and incontiguous locations (Table 6). Most of the values fall within the range of 54 to 116 ppm.

Nitrate. Nitrate nitrogen is the inorganic end product of oxidation of nitrogen-containing organic particles in water. Organic N, ammonia, and nitrate are successive intermediate stages and all are consumed by microorganisms. Bacterial processes of organic decomposition in sediments result in the production of ammonia and nitrate and the ultimate generation of inorganic nitrogen. Valiele and Teal (1974) report that N supply is one of the most important limiting factors for salt marsh vegetation. But whether or not the addition of nutrients to the soil surface will produce a significant increase in marsh plant growth seems to remain an open question. In this study, half of the plots were fertilized, and as indicated elsewhere, some significant results from the treatments were obtained for both Spartina and Salicornia. No consistent differences in N concentrations were obtained between intertidal levels, contiguous and incontiguous locations, or seasons. Concentrations ranged from 2 ppm (dry weight) to about 7 ppm (Table 6).

Regeneration of nutrients may take place in considerable amounts in the bottom sediments with subsequent diffusion into the water (Miller,

Table 7. Elements (ppm) present in substrate of the Alameda Creek experimental area, contiguous (C) and incontiguous (I) to Spartina transplants. $\overline{X}$ = means; C.V. = coefficient of variation in percent.

Month	Elev. in feet	Condition	SODIUM $\overline{X}$	SODIUM C.V.	POTASSIUM $\overline{X}$	POTASSIUM C.V.	IRON $\overline{X}$	IRON C.V.	ZINC $\overline{X}$	ZINC C.V.	LEAD $\overline{X}$	LEAD C.V.
MAY	7'	C	16000	18.7	1900	9.1	1230	20.8	6.3	9.2	<3.0	0.0
		I	13667	11.2	1767	21.4	950	54.9	4.7	32.8	3.0	0.0
	9'	C	14333	8.1	1767	6.5	790	23.7	4.7	12.4	<2.0	0.0
		I	17667	21.4	1867	16.4	1170	34.2	3.7	15.8	<2.7	21.7
OCT	7'	C	16900	16.0	1200	14.4	707	16.1	1.1	15.5	<1.5	0.0
		I	22267	13.0	1400	0.0	663	9.8	1.3	26.3	<1.5	0.0
	9'	C	17500	6.6	1167	9.9	360	18.2	1.3	26.3	<1.5	0.0
		I	19067	8.0	1100	9.1	133	48.9	0.3	0.0	<1.5	0.0

Month	Elev. in feet	Condition	MERCURY $\overline{X}$	MERCURY C.V.	COPPER $\overline{X}$	COPPER C.V.	CALCIUM $\overline{X}$	CALCIUM C.V.	MAGNESIUM $\overline{X}$	MAGNESIUM C.V.	MANGANESE $\overline{X}$	MANGANESE C.V.
MAY	7'	C	0.03	17.0	<2.23	107.6	2533	60.7	2433	13.2	63.7	38.0
		I	0.03	28.0	<0.77	7.8	3367	52.3	2100	4.8	198.7	118.3
	9'	C	0.04	0.0	<1.40	99.3	2600	49.1	2100	8.2	54.0	19.3
		I	0.04	25.2	<0.77	27.3	3400	17.6	2267	20.8	66.3	15.8
OCT	7'	C	0.22	16.6	<0.5	0.0	2467	15.3	2167	13.3	56.3	16.0
		I	0.17	15.3	<0.5	0.0	2367	19.5	2833	5.4	45.3	16.6
	9'	C	0.06	37.7	<0.5	0.0	2300	24.2	2433	4.7	40.7	4.9
		I	0.45	46.7	<0.5	0.0	3633	8.4	2633	4.4	19.3	57.1

1952; Newcombe and Lang, 1939). Insoluble ferric phosphate is reduced in the anaerobic sediments to the more soluble ferrous salt which diffuses into the tidal waters where, if hydrogen sulphide is present, it reprecipitates as ferrous sulphide with the liberation of phosphate ions. Nitrates and phosphates, as the dominant nutrients, are in a constant state of imbalance governed in large part by availability of oxygen, temperature and bacterial activity (Newcombe, Horne, and Shepherd, 1939).

Carbon. The combustible organic carbon content of sediments is a highly meaningful component since it reflects the origin of the sediment, its age, and the extent of biochemical activity. This, in turn, affects availability of nutrients needed for growth and the suitability of the substrate for metabolic processes. The mean values obtained for the experimental area range from about 5 to 17 percent wet weight. Pestrong obtained organic content levels for *Salicornia* marshlands in San Francisco Bay varying from 14 to 19 percent. Expectedly, the older established marshes have long accumulated detritus and other materials rich in organic substance, hence, the higher values than those obtained for dredge materials from the bottom of Alameda Creek (Table 6).

It is of interest to note that the May levels are uniformly about double the October concentrations. Microbiological changes that accompany the aging processes in the sediments may explain part of the reduction.

Iron, Zinc, Lead, and Mercury. These elements may be indicative of the favorability of a soil environment for plant growth. Some chemical ingredients of the soil antagonize normal uptake processes of others and are known to reduce assimulation of iron and manganese, for example (Waisel, 1972). The Atlantic cordgrass, *Spartina alterniflora*, reportedly, has a high requirement for iron. Oxygen diffusing out of its roots oxidizes some

of the precipitated iron sulphide to ferrous sulphate and thereby makes the iron available to the plant. As shown in Table 7, the iron concentrations in May varying from 790 to 1230 ug/g dry weight were much greater than those reported for October, and the coefficients of variations were not excessive. The incontiguous values for October at the 9-foot (2.7 m) level were exceptionally low in all of the replicate samples, averaging only 1.3 ug/g dry weight. The zinc concentrations ranged from about 1 to 6 ug/g dry weight of sediment. Much higher values have been reported for San Francisco Bay sediments (Peterson, McCulloch, Cosmos, and Carlson, 1972).

Lead. Lead occurs in small quantities of about 3 ppm dry weight or less. As for zinc, the October levels were consistently lower than those for May. No appreciable differences attributable to intertidal level were observed.

Mercury. The concentrations obtained for this highly toxic heavy metal were at reasonably consistent levels in the three replicates as indicated by the coefficients of variation (Table 7). As expected the levels were low, but quite variable with respect to season, averaging about 0.04 ppm in May and 0.25 ppm in October. The October, but not the May, levels were expected in light of the findings of McCulloch, *et al* (1971), who report levels commonly ranging from 0.1 to 0.5 ppm.

Copper, Manganese, Magnesium, Calcium, Potassium and Sodium. The concentrations of copper in the sediments were usually less than 0.5 ppm in October. As a trace element, it has been considered biologically important especially as a limiting factor necessary in small quantities for the setting of oyster larvae *O, virginica* (Prytherch, 1934). He considered levels of 0.2 to 0.4 ppm necessary for spat settlement. So quantities of heavy metal may be too small as well as too large to permit normal biological

activity. According to an E.P.A. Report (1972), most of the waters of San Francisco Bay were found to have concentrations of copper below detectable levels (0.01 mg/l). However, in the South Bay measurable concentrations ranged from 0.01 to 0.60 mg/l. Values of around 25 mg/kg. were obtained in sediments of the South Bay, the range for the entire Bay being from less than 1 to 88 mg/kg (Table 7).

Manganese levels in the different replicates were reasonably similar as indicated by the C. V. values. In May, at the low level of the intertidal zone and in the incontiguous position an extremely high value of 470 ppm was obtained, the other two being 68 and 58. No explanation can be offered for this high determination. Most of the other values fall within the range of 40-63 ppm. Manganese levels in fresh water sediments in the Great Lakes are reported to be much lower, around 2 to 6 ppm (Weiler, 1973).

High magnesium levels are reported here (Table 7). They range from about 2100 to 2800 ppm without evidence of consistent variation with time or place of sampling. By comparison, Weiler (1973) obtained levels ranging from 8 to 12 ppm in sediments of Lake Ontario. Magnesium is one of those elements that, if present in excess, may cause unbalanced nutrition. If present in excessive amounts in the sediments and thereupon taken up by the plants, deficiencies in other elements such as calcium or potassium may follow.

Like magnesium the calcium levels proved to be high, ranging from about 2300 to 3600 ppm. For rapid growth of marsh plants on dredge substrate, the only concern is that the levels are not excessively high or low. Unbalanced nutrition may result from the uptake of excess concentratations of calcium, magnesium, or potassium, for example. An excessive accumulation of some of these ions is known to even cause deficiencies

in others (Waisel, 1972).

Potassium. The potassium levels ranged from about 1100 to 1800 ppm and the replicates were quite consistent, the C.V. being no greater than 21 percent. Here again, the relevance in this measurement lies in its relation to marsh plant growth requirements. If the soil content results in an uptake that is too high, iron chlorosis may result (Greenway, 1968).

Sodium. As expected, the sodium concentrations in the soil are relatively high ranging from 13,000 to 22,000 ppm. The relative standard deviation (RSD), C.V. was no greater than 21 percent. The October levels were higher than those for May which is to be expected (Table 7).

In general, there is no evidence of an excessive elemental content of the dredge substrate considering the tolerances of the plants. Cordgrass is well adapted to withstanding extremes of emersion and has deep, well aerated root systems enabling it to overcome extremes of tidal action. Being a nonsucculent halophyte it possesses a high capacity for resisting salts by desalination of its tissues. Any excessive salt content of such plants is secreted through salt glands.

E. Planting Effort

The cost of planting a marsh cannot be limited only to the collection time and planting effort. Other expenditures that have to be charged against the number of plants collected for marsh restoration include: costs of labor, transportation, collection equipment, and the processing of the plants (Table 8). Included in the processing are such items as: fertilizers, holding and transport tank facilities, pumps, pipe, water, and power costs. All of these factors assume increasing proportions in any large scale marsh restoration project.

The field collection of marsh plants can utilize a number of methods depending upon the location of the plant sources and the conditions

of the substrate. Different methods include: collection from a boat during high tides while lower marsh zone plants are covered, wading out to marsh areas at low tides, and the construction of planks or boardwalks onto excessively soft substrate collection areas. The tide is the main factor to be overcome in making collections from the lower intertidal marsh areas. Collection periods during the day are limited by access time to lower marsh areas because of tidal action.

In the planting of areas of marsh, items that must be taken into consideration include the breaking-up of large plugs into smaller planting units which can be individually planted. Moving planks or boards on the experimental site to facilitate planting, transportation of crews and materials to and from the site, loading and unloading of materials and equipment, and the recording of observations on growth and survival (Table 8).

At present, it is believed that the use of seed may constitute the most effective and least expensive planting method. However, the transplanting of plugs and rooted cuttings yields more biomass per unit effort during the first year of growth and in certain instances may be the preferred method. But, under favorable seed survival conditions, seeds yield a higher number of plants per unit effort. So, given time and a high percent of survival, maximum production is assured.

Regarding *Salicornia*, the number of man-hours required to plant 1,000 square meters with rooted cuttings and seedlings is about the same as for *Spartina*. Expectedly, a relatively short time is required to plant unrooted cuttings (shoots) of *Salicornia*, namely, 22 man-hours, per 1,000 square meter (Table 8).

Table 8. Estimates of Planting Effort

METHOD	OPERATION	Estimate of man/hrs. required to plant 1000 sq. m.	
Spartina seeds	Collection of seeds	1.5	
	Storage preparation	2	
	Storage maintenance	10	
	Planting - field	19	Σ = 30.5
Rooted Cuttings	Collection	7	
	Preparation	7	
	Planting - nursery	40	
	Nursery maintenance	30	
	Planting - field	37	Σ = 121
Seedlings	Collection	1.5	
	Preparation	7.5	
	Planting - nursery	40	
	Nursery maintenance	30	
	Planting - field	37	Σ = 116
Plugs	Collection	9.1	
	Preparation	20	
	Planting - field	57	Σ = 86.1
Salicornia Rooted Cuttings	Collection	4	
	Preparation	4	
	Planting - nursery	40	
	Nursery maintenance	30	
	Planting - field	39	Σ = 117
Shoots (Unrooted Cuttings)	Collection	4	
	Preparation	4	
	Planting - field	18	Σ = 22
Seedlings	Collection	8	
	Preparation	2	
	Planting - nursery	40	
	Nursery maintenance	30	
	Planting - field	33	Σ = 113

VII. DISCUSSION

The survival of seeds, hand-sown on marshland surface, is dependent on firmness of the surface of the substrate and its moisture content, and upon wave action. Presumably, raking-in of the seed enhances its survival and germination potential. The part of the intertidal zone at which seeds of Spartina foliosa or Salicornia pacifica survive to produce seedlings is also a function of elevation. The results show that, for Spartina, fertilization is not overall a significant factor in determining seed survival or, indeed, the growth of any of the four growth forms. According to Purer (1942) and others, seedlings are uncommon in natural areas, the spread of cordgrass being due mainly to vegetative growth. However, in the Alameda Creek situation, hand-seeded plots had numbers of seedlings, a maximum of 134/25 m^2 plot, that are significant in terms of the numbers needed to establish cordgrass cover on a bare marsh surface within a reasonably short period--perhaps within 3 years (Appendix F, Tables 1 and 2). It is believed that use of seed dissemination is commercially feasible, at least in some marsh areas, given adequate practical methods and equipment for collecting the seeds, for sowing, and raking them in. Pickleweed is known to establish itself readily by means of seeds if the intertidal level and surface texture are favorable. Nursery grown stock produced abundant seed that spread naturally in the experimental growth boxes containing dredge material and other substrates. No limiting effect of soil type was observed.

The high survival of robust Spartina plugs in the plots, namely, 77 to 83% in October, is to be expected (figure 1). The larger transplants are better able to withstand the shock. Although the combined plot means seemed to show a higher survival of these particular transplants in the

fertilized plots, the 3-way analysis of variance revealed no significant interaction. For practical applications, the data suggests a need for an experimentally designed program to include more specific treatment of the factors that are operating to affect survival and growth of the 5 growth forms. One specific consideration is the possible shock effects accompanying transplantation from one salinity regime to another. A second consideration is to measure, by radioactive tagging or other means, the physiological as well as the environmental fate of the nutrient elements in relation to their availability to the plant roots. Tidal action, air movements, and ready solubility in tidal waters are factors that can dilute or completely isolate the nutrient source that is intended for the plant. In certain instances the positive effect of fertilization was limited to the May - August period suggesting that not enough fertilizer remained thereafter to alter the normal pattern (figure 3).

Number of stems is considered a highly useful index of soil suitability for developing plant cover (figure 2; table 2). There is relatively more subsurface plant tissue in young cordgrass plants. If soil is to be a limiting factor, then root growth might reflect the dominant effect. Dieback of stems was readily observed in July and measured in August. But it created an exaggerated impression, since the growth of shoots soon registered the fact of subterranean growth and positive evidence of subsurface root spread--an important consideration for producing substrate cover. The primary practical consideration for plant production is numbers of survivors per unit area of soil surface. The number may be small yet in relation to the known amount of annual spread of a single plant, a survival of as few as 3 healthy plants per 25 meter square area would assure a relatively rapid spread of cordgrass over a bare substrate. Professor H. Thomas Harvey

obtained a spread of about 3 meters for one plant during an 18-month period at Faber Tract in South San Francisco Bay.

An average linear growth of seedlings of 12 cm. from May to October in dredge material appears acceptable in practical terms (Table 2; figure 3). But, the increment for a more normal substrate under typically natural conditions is not known. In the nursery a somewhat comparable mean increment of 8.5 cm was obtained for a mixture of one quarter dredge material and three quarters sand-vermiculite mixture during a 12-week period 7/10 to 10/30/1974.

Other aspects of the cordgrass experimental data accruing from the investigation that merit attention pertain to the relative amounts of standing biomass below ground and aboveground. Of particular botanical interest is relative growth of plant parts--ratios of aerial to subsurface of the plants (Plate 3). The relative growth of parts of organisms has been investigated extensively since the classical work of D'Arcy Thompson (1917) and Huxley (1932). While the nature and extent of variations in relative growth rates of body parts of invertebrates have been investigated* (Newcombe, et al, 1936, 1937, 1948), comparatively little work has been done on differential growth rate in plants. The area of the plant surface aboveground would probably be a more sensitive index of growth but unfortunately no such data are available at this time.

Environmental factors may alter the normal shoot-root weight ratios (Table 4). If dredge material is an abnormal substrate for plant survival and growth, this condition might be revealed by an abnormal ratio

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*Related mammalian studies on the relative sizes and growth rates of body parts in humans with emphasis on their etiological implications, have been pursued by Professor Albert R. Behnke, Jr. at the University of California Medical School, San Francisco.

of weights of body parts. Unfortunately, the ratios that apply under normal conditions are not known at this time. But the variations encountered in this study can properly be recorded and interpreted in light of known environmental variations at the experimental site (Tables 2 and 3).

It is of interest to compare the actual mean weights of the shoots versus the roots in the five growth forms during May - October period which may approximate an annual growth figure although the 1974 increment prior to May 15 is not known (Table 4; figures 7 and 8).

Seeds planted in mid-May produced in unfertilized plots by October 0.30 g. of shoot dry weight and 0.37 g. of root dry weight. Corresponding figures for seedlings are 0.48 g. and 0.87 g.; robust rooted cuttings, 0.87 g. and 5.02 g.; dwarf rooted cuttings, 0.59 g. and 1.76 g.; and for robust plugs, - 4.08 g. (due to die-back) and 6.23 g. (Table 2).

Regarding Salicornia plantings that occupied the approximate 9-foot (2.7 meter) intertidal level, the statistical analyses revealed a significant interaction due to fertilization. The survival rate obtained, namely, between 48 and 92% for planted seedlings and rooted cuttings, is adequate for practical purposes (Table 3). The unrooted cuttings sown on the surface failed to survive in almost all instances (figure 4). Because of the relatively low cost of planting a suitably situated marsh area with seed (not tested here) and vegetative cuttings, effort should be directed toward developing a specifically designed inexpensive technique for raking in the unrooted vegetative cuttings to assure a percent recovery adequate for practical purposes. Only about a half-dozen per 25 m^2 area should suffice. In some areas seed are easy to collect in commercial quantities. To determine experimentally the best method for their storage and dissemination offers no problem. As shown in Table 3, and referred to elsewhere

the numbers of stems increased rapidly particularly during the August - October period (figure 5). From around 16 to 26 stems per seedling were grown during the May - October period. Rooted cuttings were likewise prolific.

The growth in height data are adequate to show that once a Salicornia seedling or cutting is established, the subsurface environment is sufficiently favorable to produce needed plant cover in a reasonably short period of time. During the May - October period, seedlings grew, on the average, about 14 cm and 21 cm in unfertilized and fertilized plots, respectively, (Table 3; figure 6).

Regarding weight increments, shoot growth in Salicornia greatly exceeds root growth--a reverse of the ratio in Spartina (Table 4). Unfertilized seedlings gained about 10 g. and fertilized ones about 30 g. in shoot dry weight during the May - October period, these increments representing highly significant differences. Corresponding root dry weights of seedlings were only 2.4 g. and 2.5 g., respectively. With time, the shoot-root ratios will doubtless vary in both Spartina and Salicornia, but there appears to be no evidence of growth retardation due to the soil factor (Tables 2 and 3; figures 7, 8, and 9).

The invastion of a newly exposed marshland by a subterranean fauna is dependent, in large part, upon the plankton populations of the tidal waters and the downstream creek water quality. Further difficulty in prediction results from lack of knowledge of the life history stages, spawning seasons, and the times of setting of several of the dominant plankters. Periodic plankton tows in Alameda Creek and in adjacent areas together with benthic quantitative samplings in a control area would assist in evaluating the suitability of dredge material for producing biomass. Additional samples in the experimental area would yield a more complete picture

of the nature of the infauna and the extent of the invertebrate invasion. However, the positive plant survival and growth data and the lack of exceptionally high levels of toxic chemicals that might prove deleterious for the sensitive larval and early developmental stages of the invertebrate fauna, suggest that the dredge material is conducive to the establishment of a normal subterranean population (Table 5). No questionable physical properties of the substrate were revealed in this study that warrant further analysis. The leveling process in the intertidal zone established essentially two minature plateaus at intended elevations about 7' and 9' (2.1 m and 2.7 m) above MLLW. They presented quite irregular plot surfaces in the beginning but, with time, have tended to flatten out. There is evidence that such irregularities of terrain with shallow tidepool depressions are, in certain instances at least, responsible for growth variations encountered in parts of this study.

Regarding expenditure of effort to plant a bare area of marsh, much depends on the softness of the substrate, and hence its accessibility for mechanical operations. There are vehicles well adapted for such purposes. Most any hand-planting operations apart from seed applications are costly. Further studies on the application of seeds for cordgrass development, and seeds plus rooted and unrooted cuttings for pickleweed may be expected to yield positive, commercially useful, results. It is seen in Table 8 that about 30 man-hours may be required to seed 1,000 square meters (about one-quarter acre) to cordgrass, i.e., about one-third of the time required to plant that area with plugs. There are of course the factors of increased stability of the plug plantings and their advanced state of growth at the end of the first growing season which favor plugs. However, if time is not a factor, the ground cover produced by planting seeds may soon overtake

that produced from plugs. Salicornia seeds quite readily by natural means. Based upon the Alameda experience the number of man-hours required to plant 1,000 square meters with seedlings and rooted cuttings is about the same as for Spartina plants. Relatively little time is required to plant shoots or unrooted cuttings--about 22 man-hours. By improving the method of application, the low survival rate of 10 to 30 percent could probably be greatly improved and thereby hasten the production of ground cover for marsh restoration (figure 4; Table 8).

VIII. SUMMARY AND CONCLUSIONS

A. Summary

In this study cordgrass, Spartina foliosa Trin., and pickleweed, Salicornia pacifica Standl., were planted experimentally on intertidal dredge material substrate. Plant growth and environmental factors affecting survival and growth of the plants were measured. Nursery grown stocks of Spartina seedlings, robust rooted cuttings, and dwarf rooted cuttings, along with robust plug transplants, and seeds from natural areas of marsh were selected for study purposes (plate 2). The Salicornia growth forms employed were nursery stocks of seedlings, rooted cuttings, and unrooted, vegetative cuttings.

In addition to controls, 66 experimental plots, half fertilized and half unfertilized, 5 by 5 meters in size were planted in mid-May along with 14 transects of Spartina plugs (plage 5) and 4 transects planted with seeds of Spartina foliosa Trin (Appendix H). Records of survival and linear growth in the fertilized and unfertilized plots were made in mid-August and late October. The growth indices of size selected are: numbers of shoots, linear plant measurements, and weights of aerial and root parts of the plants. Attention was given to the extent to which volunteers of both species invaded the plots (Appendix F). Some records were made of growth of several plant forms taking place in the Point San Pablo Laboratory nursery of the Center (plate 2). Also, records were taken of the man-hours effort required to pursue specific aspects of the work (Table 8).

Invasion of the fresh, unpopulated dredge material by benthic invertebrates was recorded in October (Table 5).

The environmental factors of the substrate that were measured include: moisture, substrate compressive strength, particle size of the

sedimental substrate, its chlorinity, alkalinity, total organic carbon content, nutrient content, redox potential, and ten chemical elements, all of which serve as indices of favorability of the soil environment for growth of marsh plants (Tables 6 and 7).

Because the oxidation-reduction potential of the dredge material may exercise a dominant effect on the germination of seeds and the growth of marsh plants, special attention was given to the redox potentials in the several environmental situations (Appendix A). Elevation is a dominant ecological factor limiting distribution and growth of intertidal organisms, hence, it was the subject of several intertidal transect studies of cordgrass plugs using robust and dwarf ecophenes (Appendix B). Morphological and anatomical descriptions of Spartina foliosa Trin. with emphases on the aerenchyma tissue for downward transport of oxygen to the root system were completed for the first time (Appendix C). The cytogenetic studies provided needed information on the chromosome composition of the robust and dwarf growth forms of Spartina foliosa Trin. (Appendix D). Physiological laboratory experiments demonstrated the downward passage of oxygen transport from leaves to root systems of Spartina foliosa Trin. (Appendix E). Appendix F presents the data on volunteers that invaded the control plots. The last two appendices have been reserved for presenting much of the original growth data that is not contained elsewhere in the report (Appendix G, Tables 1 to 10; Appendix H).

B. Conclusions

1. Environmental Conditions.

a. The dredge material substrate of the experimental area is composed primarily of particles of silt and clay. Between 82 and 94 percent (dry weight) are less than 32 microns in diameter (Table 6).

b. There is relatively little difference in the substrate compressive strength between cores taken in the A plots at about 9 feet (3 meters) above MLLW and the control cores taken from an unplanted area at this level. The compressive strength values range from about 350 to 442 pounds per cubic foot (5.6 to 7.1 kg per square decimeter). It is concluded that the compressive strength levels may be expected to increase as the biotic succession continues.

c. Except for low oxygen levels, there is no evidence of excessive or limiting elemental content in the dredge material substrate of the experimental area, considering the tolerances of the dominant plants (figure 6).

2. <u>Evidence of suitability of dredge material for producing vegetation</u>

a. The proper application of viable <u>Spartina</u> seeds may be an economically sound method for producing plant cover on fresh dredge material. With the adequate physical conditions of the substrate and the suitable application method (raking-in) of this study, seedling survival from August to October may exceed 50% (figure [illegible], Table 2).

b. The spread and survival of <u>Salicornia</u> seed is not expected to be a practical problem. This conclusion is based on observations in nature and the results of natural seeding in the nursery.

c. All growth forms or starter-types of <u>Spartina</u> plants in all plots survived above the 50% level, except for robust rooted cuttings (figure 1; Table 2).

d. Of the three growth forms of <u>Salicornia</u>, seedlings and rooted cuttings survive in significant numbers (figure 4; Table 3). The survival of rooted cuttings was significantly different in the fertilized and unfertilized plots--92% and 57%, respectively.

e. The number of stems of Spartina is a very realistic index of growth (figure 2; Table 2). Here, an overall positive effect of fertilizer on all growth forms or starter types may be expected. During the 5-month period the number of stems increased by an average of about 6 for seedlings, 2.2. for robust rooted cuttings, and 3.5 for dwarf rooted cuttings.

f. The number of stems index of growth for Salicornia seedlings responds positively to the application of fertilizer (figure 5; Table 3). For the 5-month period, an average increase of 26.3 stems of seedlings took place in the fertilized plots and 15.9 in the unfertilized plots.

g. Height measurements of Spartina reveal no overall differences attributable to fertilizer (figure 3; Table 2). During the immediate afterplanting period, a conspicuous die-back of the culms and leaves of the cuttings and plugs occurs due, it is believed, to shock from handling the plants. The original height may not be exceeded significantly the first growth season, but thereafter a rapid growth in height and lateral spread is assured.

h. The absolute increments of shoot growth in height from seeds of Spartina during the May - October period averaged about 17 cm. The mean growth of seedlings was around 12 cm. (figure 3; Table 3).

i. Growth in aerial height or length of Salicornia is conspicuous, there being a modest effect of fertilizer on seedling growth (figure 6; Table 3). Whereas, the seedlings are not expected to dieback immediately after planting, rooted cuttings may do so and thereafter grow well.

j. Absolute increments of growth in height of Salicornia transplanted seedlings during the May - October period averaged 14.4 cm in the unfertilized plots and 20.9 cm in the fertilized plots (figure 6; Table 3).

k. There is no overall effect of fertilizer on dry weights of _Spartina_ shoots and roots. Furthermore, the data of this study show that there is no significant effect on any of the individual growth forms (figures 7 and 8; Table 2).

l. _Spartina_ shoots of transplanted seedlings increased in dry weight during the May - October period 0.68 g. in the fertilized plots. The corresponding mean, dry weight increase of the roots was 1.30 g., the ratio being 1:1.9.

m. While aerial parts of _Spartina_ undergo dieback following planting, roots do not. Hence, dieback is attributed to shock of transplantation and not to an unfavorable property of the soil.

n. Root growth in _Spartina_ is much greater than shoot growth in all of the growth forms studied (Table 4).

o. Robust root cuttings of _Spartina_ grew faster than dwarf forms at the 7-foot (2.1 meter) level.

p. An overall positive effect of fertilizer on shoot weights of nursery rooted _Salicornia_ seedlings is reported, the ratio to unfertilized mean weights for seedlings being 3:1, the absolute growth increments being 30 g. and 11 g., respectively (figure 9; Tables 2 and 3).

q. Initially, fertilized _Salicornia_ rooted cuttings outgrow, in weight, the unfertilized plants, in this case by a ratio of 4:1. At this point in the experiments, it is not possible to assign a priority to nursery rooted cutting transplants versus nursery rooted seedlings (figure 9; Table 3).

r. _Salicornia_ shoots of transplanted nursery rooted seedlings increase in dry weight far in excess of the roots. Whereas the shoot increase here was 29.9 g. in the fertilized plots, the corresponding mean,

dry weight increase of the roots was 2.5 g., the ratio being about 1:0.08. Thus, the root weight increased was only 7.7% of the total dry weight increases for Salicornia compared to 60% for Spartina (figure 9; Table 3).

s. _Spartina foliosa_ Trin. plants used in this study had a root biomass weighing about 74% of the plant, whereas, in _Salicornia pacifica_ Standl. plants the root biomass only comprised about 14% of the total weight of the plant (Table 4).

t. Since scarcely any _Spartina_ volunteers were found in the control plots in August or October, it may be concluded that, at least in some localities, other means must be found to develop cordgrass cover for bare marshlands (Appendix F, Table 1).

u. Natural seeding of suitable marshland by _Salicornia pacifica_ Standl. is likely to prove adequate for a reasonably rapid production of pickleweed cover on bare marshland (Appendix F, Table 2).

v. Invasion of the bare, intertidal, experimental plots during May to October, by benthic macroinvertebrates was characterized by unexpectedly low numbers of species and organisms. The dominant invaders were amphipods. Only a few of two species of polychaetous annelids were collected. It is postulated that an insufficient number of samples were taken to provide an adequate assessment of the October, invertebrate population (Table 5).

3. Information on growing marsh plants in dredge material.

a. A limiting factor governing the amount of effort required to plant a bare area of marshland is its softness and, hence, accessibility for mechanical operations. Apart from seed applications, almost any hand-planting operation is relatively costly. Much depends upon the scale of the marsh restoration effort. The larger the project, the cheaper the cost per acre.

b. The planting effort required when using Spartina seed is about 30 man-hours per 1,000 square meters of marshland. The corresponding time periods for rooted cuttings, seedlings, and plugs are 121, 116, and 86 man-hours.

c. The man-hours of effort required to plant 1,000 square meters with Salicornia rooted cuttings and seedlings is about the same as for Spartina rooted cuttings and seedlings, namely, 117 and 113 man-hours, respectively.

4. Anatomy, physiology, and cytogenetics.

Special studies presented in Appendices C, D, and E permit the following conclusions:

a. The anatomy of Spartina foliosa differs in certain structural details from that of Spartina townsendii, the European species. For example, whereas the rhizomes of S. townsendii are fleshy and flaccid, those of S. foliosa are firm and rigid containing well-developed sclerenchymatous tissues of many layers in thickness.

S. foliosa possesses two kinds of roots, namely, thick, unbranched anchorage roots and thinner, profusely branched absorption roots. The anchorage roots penetrate deeply into the substrate while the absorption roots ramify profusely forming an intricate mat in the upper soil layers. To quote from Professor Kasapligil's Appendix C, "..., the ecological anatomy of Spartina foliosa is quite similar to that of S. townsendii while these two taxa differ from each other in certain details...."

b. Regarding the chromosome numbers in the dwarf and robust growth forms of Spartina foliosa, "the diploid chromosome number for both forms of Spartina foliosa was determined to be 2N = 60 (figures 1 and 2). The previously published chromosome number for the species, 2N = 56 (Church, 1940) appears to be in error. There was no evidence that the two forms of

Spartina foliosa represent different polyploid races." (from Professor Dennis R. Parnell in Appendix D).

c. Spartina foliosa plants growing in relatively anaerobic soil give evidence based on redox potential data of release of oxygen from the root system to the adjacent soil layers (Appendix A by Messrs. C. R. Pride and D. E. Lingle). On the basis of laboratory physiological experiments, Mr. Geoffrey Wong was able to conclude that, "S. foliosa does conduct a certain amount of oxygen to the medium surrounding its roots." He further states, "that the Spartina plant can supply not only enough oxygen to fulfill the needs of the roots, but in addition it can supply a certain amount to the water surrounding the roots." (Appendix E)

IX. RECOMMENDATIONS

This study has provided information on procedures for establishing intertidal flora upon dredge material. It is believed that the findings may be applied to existing marsh soils as well. Of course, informational gaps still remain. So some of them are given here in the form of recommendations for further study to remove certain practical limitations to successful farming of intertidal marshlands.

It is recommended:

1. That the Alameda Creek studies be continued until at least October, 1975 to complete current studies of methods for producing plant cover on bare dredge material;

2. That, because of the cost of large-scale planting operations, special attention be given to practical ways of utilizing seed and seedlings for producing plant cover. Information is needed on inexpensive methods for collecting, processing, and planting seeds of cordgrass;

3. That suitable machinery and methods be developed for preparing common types of marshlands in need of restoration for applications of seed and seedlings of cordgrass;

4. That current intertidal elevation studies of cordgrass ecophenes be enlarged to evaluate the practicality and the methodology for growing cordgrass at the upper and lower extremes of its intertidal distribution. This recommendation is prompted by the apparent existence of extensive marshlands in need of restoration that are situated somewhat below and above the intertidal zone of maximum productivity, and yet possessing potential for cordgrass growth;

5. That an investigation be made of the several alternative methods and times of applying fertilizer during the establishment and recovery

operations of marshlands for cordgrass production; and

6. That field experiments be conducted to evaluate the usefulness of cordgrass seeds, seedlings, cuttings, and the two transplant types of plugs, for stabilizing and providing plant cover in tidal shore areas of meanders, creeks, and bay frontage exposed to heavy flow of water and/or wave action.

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XII. APPENDICES A TO H.

APPENDIX A

REDOX POTENTIALS IN SOIL ENVIRONMENTS OF CORDGRASS, SPARTINA FOLIOSA TRIN.

by

Charles R. Pride and Donald E. Lingle

1. INTRODUCTION

Redox potential (E_h) determinations refer to oxidation-reduction potentials of liquid or soil media. They express the difference in potential between a reference cell and a platinum electrode. In this study attention has been given to the use of oxidation-reduction potentials as indices of soil stagnation in the immediate and distant environments of cordgrass plants. Geoffrey Wong's physiological experiments reported here in Appendix E suggest the existence of higher oxygen levels immediately adjacent to rhizomes of cordgrass, Spartina foliosa Trin.

Whitfield (1969) concludes that E_h measurements are operationally useful as an index of degree of stagnation of intertidal substrate. He points out that oxygen depletion is followed by nitrate reduction and then the release of toxic sulphur compounds into the water, presumably with consequent deleterious effects upon higher organisms.

While we have found little specific information in the literature on the role of root systems of marine plants in modifying the E_h levels of soil, laboratory and field studies have been made of lake sediments (Davis, 1974; Edwards, 1958). In laboratory experiments Davis (1974) found that tubificid worms increased the E_h (induced more positive readings) of profundal lake sediments at 1-4 cm depths. Edwards (1958) obtained comparable increases using chironomid larvae.

The purpose of the present inquiry has been to assess the redox potential levels in the dredge material at the Alameda Creek experimental area and to compare such levels with those of natural marsh substrate and dredge material in the cordgrass experimental growth tanks of the Point San Pablo Laboratory nursery. The data, albeit of a preliminary nature, are indicative of the chemical interaction and stress of the immediate, somewhat rigorous, plant environment provided by dredge material.

2. OBJECTIVES

The E_h measurements were made to help characterize the dredge material as a medium for survival and growth of marsh plants. Cordgrass has long been known to grow under anaerobic soil conditions. Reportedly, it is the only phanerogam to grow luxuriantly on the Palo Alto marsh (Hinde, 1954). This is attributed to the presence of aerenchyma tissue that makes possible the transfer of oxygen from the plant leaves downward to the subsurface rhizomes and roots, (Appendix E).

The study aims to increase knowledge of marsh conditions under which cordgrass will grow. An understanding of the redox potential of surface and subsurface layers of dredge material, and of normal marsh substrate that supports a growth of cordgrass is highly pertinent ecologically. Also, the levels of the redox potential at the soil depth of the plant root system adjacent to and removed from the plant may help explain the relative unique capability of cordgrass to populate anaerobic dredge material in the marsh environment.

3. METHODS

For E_h measurements a platinum electrode and a calomel reference electrode were used. The redox potential is the difference in potential between a reference cell, usually calomel, and a bright

TABLE 1

Factors assumed to be operative at E_h levels of soil substrate* (based on varied literature sources)

E_h levels	Operating factors
+ 300	oxygen present for long period
+ 200	soil somewhat oxygen depleted, biological activity is probably using NO_3^- as the electron acceptor
+ 100	NO_3^- is electron acceptor
0	SO_4^{-2} is electron acceptor and HS^- is probably being produced
- 100	SO_4^{-2} is electron acceptor and large amounts of HS^- are present

*This table was prepared with the assistance of Doctor Jerrold Jayne, MRC consultant and Professor of Chemistry, San Francisco State University.

TABLE 2

E_h measurements in millivolts at Alameda Creek to show differences between the redox potential adjacent to and away from cordgrass plants in June, August and October 1974, Plot B, Position 47-25. (Plate 5 and Table 1, Section II).

June 17/74		August 30/74		October 22/74	
Contiguous	Incontiguous	Contiguous	Incontiguous	Contiguous	Incontiguous
+101	-4	+206	76	+126	-134
+216	+136	-104	116	-64	-64
-6	+106	+236	116	+56	-104
-134	-54	+316	156	+146	-134
26	-34	+256	236	+156	+96
-64	+66	56	246	+180	+46
56	+26	316	216	+206	-154
46	-14	266	26	+96	
126	-144	346	176	-54	
-54	-144	116	236	-4	
				+146	

platinum electrode. Potentials are referenced to a hydrogen electrode with hydrogen gas at standard temperature and pressure. The $H_g \| H_{g2} Cl_2$ reference potential is subtracted from the total measured potential to give the potential at the platinum electrode.

The difference in potential was measured with a portable FET-input millivolt meter. To avoid ground loop problems, the millivolt meter was carried in an insulated box which isolated the meter electronics from the marsh mud electrical ground.

Exploratory E_h readings were taken at several depths below the mud surface to assess possible variation with probe depth. Previous erratic data indicated the need for vertical profiles. Measurements were made contiguous to the plant stem and at intervals outward for a total distance of 12 inches. They were repeated for several depths of the platinum electrode.

To help evaluate the redox potential of dredge material as a factor in marsh grass habitat, measurements were made in a normal cordgrass community and in experimental tanks of the nursery containing cordgrass seedlings in dredge material that was about 3 inches in depth (Tables 7 and 8).

4. RESULTS

Based on the literature, the parameters that are assumed to be operative at different E_h levels of sediments are given in Table 1. Redox potential readings obtained at Alameda Creek during June-October, 1974, indicated somewhat lower E_h levels away from the plants growing in dredge material than adjacent to them, but inconsistencies exist in the data (Table 2). (E_h readings should be taken within 10 seconds of positioning the probe.) The cause of the observed variability of such

TABLE 3

E_h measurements at Alameda Creek to show variation with depth of substrate. Location of probe, 4 and 10 inches from cordgrass plant in Plot B; position 44-75. October 22, 1974

Location of probe from plant			
4 inches		10 inches	
Depth in inches	E_h in mv	Depth in inches	E_h in mv
1.24	+206	0.0	+146
2.0	+180	0.5	+66
3.0	+180	1.0	-74
3.5	+156	1.5	-114
4.0	+146	2.0	-134
4.5	+126	2.5	-134
		3.0	-134
		3.5	-134
		4.0	-134

readings may lie in the extent of diffusion of oxygen from the tidal waters influenced by the length of the intertidal exposure prior to making the readings (an unknown factor). Also, it may be dependent upon the depth of the probe. Certainly, these are significant factors. Two shallow 3-inch tidepools gave water readings at a 2-inch probe depth of 322 mv and 332 mv. Soil penetration by tidal waters with consequent diffusion of oxygen from the water, exposure time, and reduction processes of biochemical origin in the mud, assume importance.

The June readings at Alameda Creek were taken relatively soon after the disturbance of the intertidal dredge material that accompanied a lowering of the soil level to satisfy the marsh plant conditions for survival and growth of transplants. Perhaps due to an unconsolidated physical condition of the substrate, and a plant condition still in a state of shock from the transplant operation, somewhat erratic E_h determinations were obtained (Table 2). In August the contiguous E_h readings were nearly all positive, ranging from -104 to +346 mv. This relatively consistent picture suggests a lesser degree of stagnation contiguous to the plant. The relatively natural substrate (non-dredge material) at Point Molate marsh (Table 7) situated on the east side of Central San Francisco Bay yielded quite comparable E_h data.

E_h readings in the Alameda Creek dredge spoil maintained at the Point San Pablo Laboratory nursery evidenced higher oxygen levels near the cordgrass. An increase in soil aeration and periodic exposure to the atmosphere would favor higher oxygen levels in this substrate.

The extent of variations in redox potential accompanying increase in depth of the probe in the soil is shown in Table 3. At depths below 2 inches, quite similar E_h readings were obtained. But

consistently lower readings were associated with increased distance from the plant. At a 10-inch distance from the plant, lower values predominate. As indicated in Table 4, positive or slightly negative levels occurred near the plant. These data and a number of isolated readings indicate that lower readings may frequently occur at and below a depth of 5 inches. Using a probe depth of only 1 inch gave almost entirely positive readings at various lateral distances from the plant (Table 5). The nature of the variation in E_h readings that may be encountered with increasing probe depths and lateral distance from the plant is shown in Table 6. Here, negative values were obtained, quite consistently at the 5-inch depth.

Shallow depth E_h values seem to exhibit a cyclic variation at lateral distances from the plants, with the period of the cycle varying from 2 to 4 inches. E_h values are usually low immediately adjacent to the plant, increasing at 2-3 inches away from the plant, then decreasing again. In some cases a second high E_h peak is observed developing at less than 10 inches away from the plant. This phenomena is also observed at depths of 2-5 inches below the surface.

A useful method of presenting the data is to contour E_h values at various subsurface depths and distances from the plants. Contours were made of two plots to the nearest 100 mv. They show a tongue of +40 mv sediments extending out and down from the plant, underlain by -50 mv sediments, with shallow intrusions as high as +200 mv occurring near the surface. It is of interest to compare these relationships with those indicated in Tables 7 and 8 for non-dredge material studied November 26, 1974, at the Point Molate marsh on the east shore of central San Francisco Bay and in dredge spoil material of an experimental

TABLE 4

E_h measurements at Alameda Creek to show variation with lateral distance from cordgrass plant at a probe depth of 3 inches in the substrate in plot B, position 44-75. October 22, 1974.

Test 1

Distance in inches to Creek from plant	E_h in mv
0.5	-14
2.0	+96
4.5	+196
4.5	+196
6.75	-64
8.25	-104
10.0	-134

Test 2

Distance in inches to Creek from plant	E_h in mv
Adjacent to plant stems	-54
0.5	-4
2.5	+146
4.5	+46
6.5	+96
8.5	+46
10.5	-154

Test 3

Distance in inches from plant from Creek	E_h in mv
2	+66
4	+66
6	-114
8	-94
10.5	+186

Test 4

Distance in inches from new plant to Creek-Drier substrate Depth of probe = 1 inch	E_h in mv
Beside plant	-104
2.5	+36
4.5	-34
6.5	+126
8.5	+76
10.5	+86

TABLE 5

E_h measurements at Alameda Creek to show variation in lateral distance to Creek in substrate of Plot B, position 46+00. Depth of probe in substrate = 1 inch October 22, 1974.

Plant 1

Distance in inches from plant to Creek	E_h in mv
next to plant	+56
2.5	+136
4.5	+6
6.5	+146
8.5	+176
10.5	+296

Distance in inches from plant to Creek	E_h in mv
next to 2 plants	-134
2	+26
4	+36
6	+96
8.5	+36
10.5	+56

tank, number X3, at the Point San Pablo Laboratory nursery. Positive readings were obtained, with one exception, at all depths at 1" and 2.5" from the plants. Again, non-dredge material conditions and laboratory conditions under which dredge material is maintained were examined in greater numerical detail at Castro Creek on September 3, and in the nursery 9/5/74. The intertidal marsh is situated on the south shore of San Pablo Bay near Richmond. The incontiguous readings of the laboratory dredge material (from Alameda Creek) in experimental tanks were in most instances equal to or lower than the contiguous values, but far from being negative (Table 9). The tank data cannot be properly related to field records since the tank soil is drained periodically and the general maintenance regime would favor an aerobic environment.

5. DISCUSSION

Although redox potential measurements of intertidal substrate, which commonly range from -200 to +250 millivolts, are only reproducable to within about ± 15 percent, they are operationally useful as an index of degree of stagnation of intertidal substrate (Whitfield, 1969). Negative E_h potentials indicate an anaerobic environment in which biological activity is using chemical species lower in the electromotive scale than oxygen (Table 1). After oxygen depletion NO_3 first acts as an electron acceptor and then lower down on the electromotive scale, SO_4^{-2} is the electron acceptor.

In addition to indicating the oxygen depletion of the environment, the E_h potential, together with the pH, can be used to calculate relative solubilities of various cations in the mud. The equilibria of the most abundant element, iron, are treated extensively by Cooper (1957). Cooper derives the following equation for the ferrous-ferric system in

TABLE 6

E_h measurements at Alameda Creek to show variations with depth of substrate and distance from cordgrass plant. Plots A, B, and C. Position 44+75. October 29, 1974.

Distance from plant	Depth of Probe in Inches								
	Plot C, Test 1			Plot B, Test 2			Plot A, Test 3		
	1	2.4	5	1	2.5	5	1	2.5	5
0	+66	-34	-54	+346	+256	-114	+96	-64	-104
2	+6	-64	-54	+426	+306	-4	+36	+146	-4
4	-34	+6	-54	+296	+296	-104	-154	+46	-154
6	-14	+46	-54	+306	+296	-34	+36	+66	-44
8	-34	-24	-54	+286	+286	+86	+156	+66	-4
10	-54	-4	-34	+266	+286	+276	+66	+186	+46
12	-54	-104	-34	+296	+286	+276	+196	+96	+56

TABLE 7

E_h measurements at Pt. Molate Marsh (Central Bay) to show variation with depth of substrate and distance from cordgrass plant. Substrate, not dredge material. November 26, 1974.

Distance from plant in inches	Depth of probe in inches		
	1	2.5	5
0	+46	+104	+104
2	+146	+46	-34
4	+146	-34	-54

TABLE 8

E_h measurements in dredge material of an experimental, planted tank, X3, of the Pt. San Pablo Laboratory nursery to show variation with depth of substrate and distance from cordgrass plants under test conditions. November 26/74.

	Depth of Probe in inches								
	Plant A			Plant B			Plant C		
Distance from plant	1	2.5	5	1	2.5	5	1	2.5	5
0							+296	+246	-54
2	+271	+196	-104	+146	+46	-44	+296	+46	+46
4	+221	+46	-44	+236	+196	+146			+196
6	+196	+96	-44						

TABLE 9

E_h measurements of normal intertidal cordgrass marsh substrate at Castro Creek and of Alameda Creek dredge material maintained in a cordgrass experimental tank at the Point San Pablo Laboratory nursery.

Castro Creek 9/3/74	Point San Pablo Laboratory 9/5/74	
Contiguous to plant	Contiguous	Incontiguous
6	186	286
156	226	226
-34	136	256
136	276	296
276	246	236
296	316	156
386	326	136
186	296	196
146	306	276
156	206	176

geochemical situations: E_h - 1.011 - 0.058 log $a_{Fe^{++}}$ - 1.74 pH. If the activity coefficient of ferrous ion is taken as unity in dilute concentrations, the activity of ferrous ions is identical to the concentration. According to this equation, at lower E_h values we would expect higher concentrations of ferrous iron in solution. In sediments, this would mean that at lower E_h levels (around +150 mv) iron as ferrous ion could probably diffuse slowly to the surface.

The reduction of sulphates occurs at about an E_h of +60 to +100 mv. This generates quantities of hydrogen sulphide. Since ferrous iron appears in quantity at an E_h of 200 mv to 300 mv, ample ferrous ion is available at an E_h of +60 to precipitate Fe S causing a depletion of ferrous ion. Since the solubility of heavy metal ions is quite low in the presence of excess ferrous sulphide, one would expect increasing concentrations of Cu^{++}, Pb^{++}, Cd^{++}, and Zn^{++} ions in the mud that cannot be diffused out (Hutchinson, 1957; Hayes, 1963).

The poorly understood biochemical nature of the substrate, the relative lack of consolidation of the newly formed experimental study area at Alameda Creek, the occurrence of shallow tidepools in some of the planted plots, and the temperature variations associated with times of exposure are factors affecting the redox potential levels. But it appears that time after submergence of the substrate at which readings are taken may constitute a dominant variable. Unfortunately, such time records were not always taken. Soil porosity affecting the depth of penetration of tidal water to the subsurface layers is therefore an important consideration. Accordingly, particle size determinations were made and along with numerous analyses of the substrate are reported in the body of this report.

Clearly, from the tabular data, depth of the platinum electrode and distance from the plant are important parameters when making E_h readings. Such factors as moisture content of the substrate and the variety of chemical substances in different forms are responsible for variations in redox potential readings. The dominance of anaerobic conditions in areas of the dredge substrate as evidenced by the sulphide content is a limiting factor for plants that lack aerenchyma.

The low E_h values obtained indicate that a reducing chemical environment is present as expected, throughout the mud and one would expect quantities of sulphides to be present and a depletion of not only oxygen but the free ionic forms of cations, such as Fe^{++}, Zn^{++}, etc. Previous data obtained in this study from Pond 3 at Alameda Creek (dredge material of same origin but different age) showed generally decreasing concentrations of iron with depth (Mason, 1973). This is in keeping with lower E_h values frequently encountered at depths since soluble iron is more abundant in the low E_h environment and can diffuse out of the sediment, especially with the assistance of periodic tidal submergence. However, if quantities of sulphide become available at lower E_h levels much of the iron would be precipitated as sulphide. Measurements of sulphide content were not made but evidence from odor and appearance indicated its presence at a number of locations.

In general, the interpretation of the electrochemical potential of marsh substrate is considered difficult in a medium of such poorly understood chemical composition (Whitfield, 1969; Morris and Stumm, 1967). But the importance of redox potential in relation to the concentration and distribution of microorganisms in the littoral substrate has been recognized by marine ecologists. European studies

of oxygen conditions in sand beaches show that laterally, along the beach, subsurface oxygen conditions at corresponding depths are quite similar. According to Jansson (1967), "horizontally and vertically, however, the distribution of oxygen shows no clear trend except at the most seaward part of the beach which is the best oxygenated." But, the sand beach habitat is very different from the littoral mud zone and especially different from dredge spoil. Anaerobic conditions largely prevail and the dominant organisms are either tolerant of low oxygen content or they are, like some bivalve molluscs, able to exist deep down in the mud by means of siphons that provide direct access to surface, well-aerated waters. The consistency and the horizontal configuration of surface layers of dredge spoil, and too, the presence of small, very abundant animals are factors affecting oxygen availability to organisms, and oxygen levels, that in turn influence the distribution and numbers of, for example, turbellarians and nematodes. However, of primary interest is the biochemical metabolism of the marsh-dredge material habitat, and the amount of oxygen transported to the rhizomes and roots of the dominant marine marsh grass, Spartina foliosa Trin.

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APPENDIX B

GROWTH AND ELEVATIONAL TRANSPLANT STUDIES OF SPARTINA FOLIOSA IN DREDGE MATERIALS

by

Professor H. Thomas Harvey

INTRODUCTION

Three types of experiments have been performed over the last seven months in an attempt to determine the response of *Spartina foliosa* (cordgrass) transplants to dredge spoils at various tidal elevations. One experiment involved survival of cordgrass in dredge spoils under varying conditions of the transplant material. Another experiment attempted to ascertain the response of two suspected ecotypes of cordgrass to varied watering regimes in a laboratory setting. The other experiment involved transects of the two suspected ecotypes planted at various elevations subject to natural tidal action.

CORDGRASS SURVIVAL IN DREDGE SPOILS

A pilot study was made on the survival and growth of dwarf cordgrass cuttings from nursery stock at the Point San Pablo Laboratory of the Marine Research Center.[1] Thirty plants were planted in dredge materials on April 12, 1974. Three conditions prevailed for the test lots of ten plants each. One lot consisted of plants in 7 cm square planting pots with sand as the medium. Another lot was the same as the

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[1]Thanks are expressed to staff members Theodore Holmbeck, Meigs Mathenson, and Charles R. Pride for making the growth measurements at the laboratory nursery.

above except the pot had been removed. The third lot consisted of plants with the sand (and pot) removed, i.e., bare root. All of the plants were placed randomly in the same growing box and were watered daily by flooding and then the water was drained off. The objective of this study was to ascertain whether the presence of potting material and/or pots improved growth and survival of transplanted cordgrass into dredged material over bare root transplants.

Observations and records were made on seven occasions with the final data reported here being gathered on September 11, 1974. All twenty of the plants with potting medium around their roots survived the test period whether the pot was present or not. Only sixty percent of the bare root plants survived the test period from April to September. The first of the bareroot plants died within two weeks after planting, and three more were dead within two months.

The growth and vigor of the plants was assessed by measuring the height of plants and the number of shoots per plug that were produced. The two test lots that had planting medium around their roots did equally well. At the end of the test period the average height of the potted plants was 64.8 cm and the average number of shoots per clump was 8.5. Those with only the pot removed averaged 61.2 cm in height and 10.7 shoots per clump. The bare root plants, however, averaged only 41.4 cm in height and had 7 shoots per clump (Table 1).

Table 1. Response of cordgrass cuttings to transplanting in dredged materials

Treatment of plants	Percent Survival	Average height	Average No. of shoots
Pot and potting medium	100	64.8	8.5
Potting medium	100	61.2	10.7
Bare root	60	41.4	7.0

From the above data it can be inferred that transplanting cordgrass cuttings with pot and potting medium is better than bare root transplants. Fewer bare root transplants survived, and those that did grew less and had fewer shoots per clump than those with planting medium around their roots. Whether the pot is removed or not seems to be of insignificant consequence. Although the average height was less, the number of shoots per clump was greater in those with the pots removed as compared to those in which the pots were left on.

SUBMERGENCE REGIME STUDY

In an effort to study the response of the suspected two ecotypes of cordgrass to the amount of submergence, a tank with plants at various elevations was built at the Point San Pablo Laboratory nursery. Each of three elevations was three inches different in height. The lower elevation plants were always in water up to the substrate surface, middle elevation plants were exposed to water level at substrate level for about 2.5 hours a day, higher elevation plants were subjected to only 0.5 hours of submergence to the substrate surface. Twenty plants of the dwarf form and twenty plants of the robust form were planted at each level. The dwarf plants were cuttings which had been maintained in the Marine Research Center nursery for several months. The robust plants were recent transplants from a natural marsh. The experiment started April 16, 1974 and the following data were obtained on September 11, 1974.

At all three levels only 20 percent of the robust form plants survived, and there was no clear indication of greater survival or growth at any particular level although there was a trend toward higher numbers of stems per plug at the lower levels (Table 2). The

four plants at the lower level had 3.5 stems per plant, those at the middle elevation had 2.5 stems per plant, while those at the higher elevation had only 1.5 stems.

Among the dwarf form plants the only apparent trend that correlates with the natural habitat of the suspected ecotype, is the lower survival rate at the low elevation. The survival rate at the higher elevations was 95 percent, while only 80 percent survived at the lower elevation.

Table 2. Responses of two suspected ecotypes of Spartina foliosa to submergence.

	DWARF FORM			ROBUST FORM		
Elevation	Percent Survival	Average Height	Average No. Stems	Percent Survival	Average Height	Average No. Stems
High	95	29.9 cm	3.1	20	18.5 cm	1.5
Middle	95	38.1 cm	1.9	20	21.9 cm	2.5
Low	80	36.2 cm	2.5	20	20.3 cm	3.5

In summary, although the responses were not entirely clear, most of the data seem to substantiate the recognition of two types of cordgrass. The dwarf form is shortest at highest elevation and has more stems per planting. These characteristics are typical of natural populations. The reverse is true for the robust form which had more stems per planting at the lowest elevation. Due to the difference in treatment of source material prior to use in this experiment, it is difficult to draw specific conclusions in respect to the importance of elevation to the survival and growth of these two growth forms.

TRANSECT TRANSPLANTS AT ALAMEDA CREEK CHANNEL

On May 15 and 16, 1974 almost 300 plugs of Spartina foliosa (cordgrass) were planted at various elevations. Two suspected ecotypes,

dwarf and robust, were planted in pairs in seven transects. Five of the transects were measured as to elevation. The following table indicates the extent of the tidal range through which the transects range, (datum

Table 1. Elevation of cordgrass transects.

Transect No.	Elevation of High Plant	Elevation of low plant	Range of Transect
41+25	8.68 ft.	3.56 ft.	5.12 ft.
41+75	9.53	6.45	3.08
44+25	8.42	4.02	4.40
44+75	8.60	4.07	4.53
47.75	8.68	3.41	5.27

As of November 20, 1974, the highest elevation survivor of the robust form was at 8.44 ft. above MLLW, while the highest survivor for the dwarf form was 9.06 ft. above MLLW. The lowest survivors were at 3.84 ft. above MLLW for the dwarf form and at 3.74 ft. above MLLW for the robust form. The latter figures are not likely to be the lowest limits for cordgrass in this area as most of them represent the levels for the last plants in their test transects. The upper limits are probably more indicative of the range of the species. Only three of the 14 uppermost plants are the first in their respective transects. This suggests that those plugs that were planted higher in the other transects were at an average of 8.45 feet above MLLW while the robust form plants were in excess of their upper tolerances. The top seven dwarf form plants were at 7.78 ft. The difference between means is significant at the 95 percent level.

Survival of the transplanted plugs was based on the presence of green shoots at the planting site. The plug may be recorded as dead

at one time, but upon the emergence of a viable shoot it would be considered alive. The increase in percent of survival of the robust form at lower elevations is probably due to this phenomenon.[1] The overall survival of all the transplanted plugs was 64 percent, with the dwarf form surviving at a 78 percent level while the robust form survived at only a 50 percent level. The basic reasons for this are advanced in earlier reports.

The two suspected ecotypes seem to respond differently to the factors of the environment that vary with the tidal elevation. Specifically, high elevation plants are subject to less available water, more insulation and greater desiccation due to wind and exposure than those at low elevations. Longer submergence imposes reduced photosynthesis and stresses on gas exchange on the lower elevation plants. The present survival of the two forms is shown in Figure 1.

Although the general survival by the dwarf form was greater than that for the robust form, several other factors need to be considered. The dwarf form is, as the name implies, a relatively short plant. At the higher elevations wind desiccation will be less for such a form. Also, the number of shoots per plug are greater for the dwarf form than the robust form which may enable it to have a higher survival percentage, simply because there are more viable shoots in the transplant. On the average, dwarf transplants had 7.9 shoots per plug while robust plants had only 5.7 shoots per plug (Figure 2) in the October analysis of field experiments.

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[1]Thanks are expressed to Mr. James Harvey, senior student in marine biology at San Jose State University, for assistance in these studies.

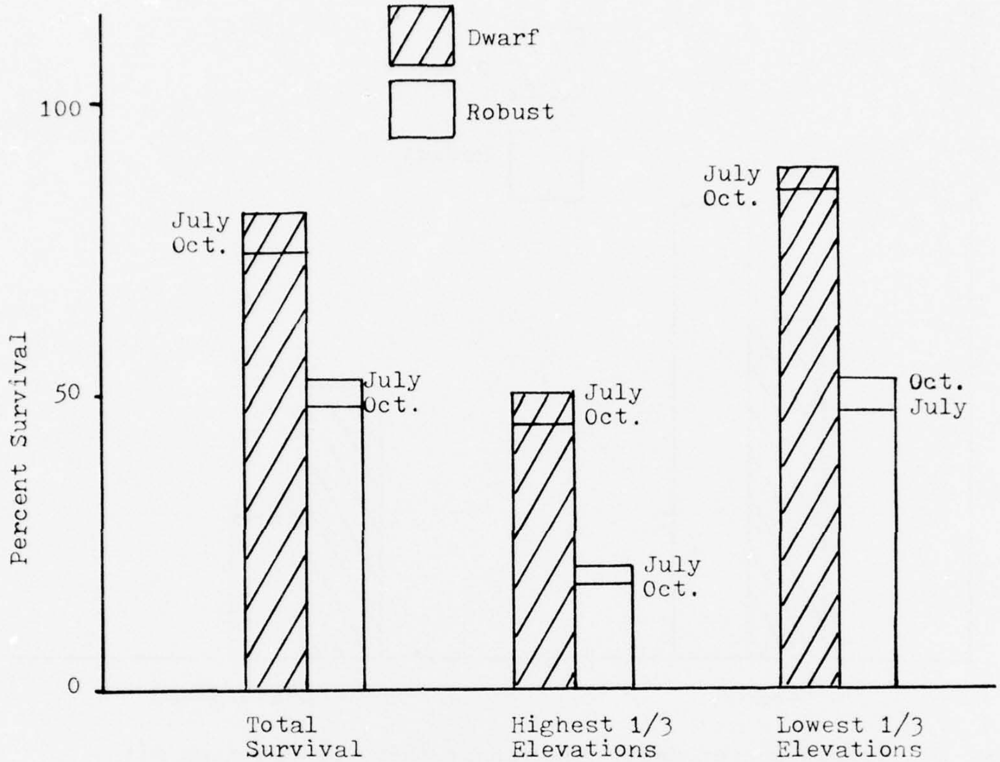

Fig. 1. Survival of dwarf and robust forms of *Spartina* at various elevations.

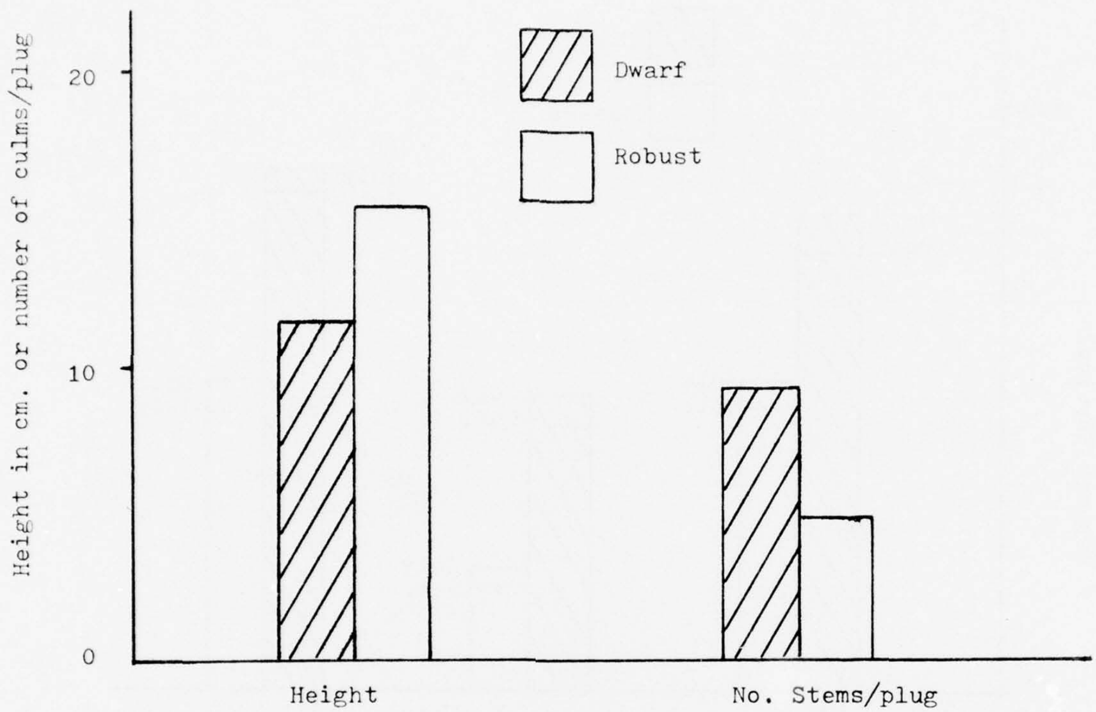

Fig. 2. Comparison of dwarf and robust forms of <u>Spartina</u> with respect to height and number of stems per plug.

At the higher one third of the elevations the dwarf form plants survived at the 45 percent level while only 12 percent of the robust form plants survived at those elevations (Figure 1). At the lower elevations both forms survived at a higher rate than their overall survival or at the higher elevations (Figure 1). The dwarf form had an 81 percent survival as of October 20, 1974. The robust form survived at a 55 percent level at the lower elevations. The fact that the only apparent increase in survival (measured by live shoots) from July to October appeared in the robust form at the lowest elevation, indicates that the robust form is better adapted to conditions at the lower elevation. However, to advance any conclusions at this date may be premature. After a full year's exposure to tidal action, a better analysis can be made.

The two forms continue to exhibit expected height levels respectively, with the dwarf form at an average of 11.9 cm for 900 shoots measured, and the robust form averaged 15.7 cm for 411 shoots (Figure 2).

SUMMARY

The pilot test of the importance of the potting medium indicates that potted plants are most successful in dredged spoils. The laboratory study of the responses of the suspected ecotypes of cordgrass to various amounts of submergence indicates that dwarf plants survive at a higher percentage at higher elevations (less submergence) than at lower elevations. Also, the number of shoots per plug for the robust form at lower elevations is greater at lower elevations than at higher elevations. This is indicative that the robust form is adapted to longer submergence times than the dwarf form.

The field trials of the two suspected ecotypes (dwarf and robust) provided data that support the contention that there are two such types. The highest mean elevation at which the dwarf form survives is statistically significant above the highest mean elevation at which the robust form survives. In addition the percent survival of the dwarf form at the highest one third elevations was almost four times that of the robust form. The survival percentages of the dwarf form and robust form at low elevations were essentially equal, (81 percent versus 74 percent or 1.09 to 1.00). Inasmuch as cordgrass can survive down to about 2 feet above MLLW in South San Francisco Bay, the survival of plants at about plus 3.6 feet above MLLW in these transects does not clearly determine the effect of long periods of submergence on the cordgrass ecotypes. It is clear, however, that in plug transplants of Spartina that overall the dwarf form plugs survived best at highest elevations (at about +9 feet above MLLW or +5 above the National Geodetic Vertical Datum established in 1929 (NGVD, 1929).

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APPENDIX C

A SYNOPTIC REPORT ON THE MORPHOLOGY AND ECOLOGICAL ANATOMY OF *SPARTINA FOLIOSA* TRIN.

by

Professor Baki Kasapligil

Spartina or Cord Grass is a member of the family Gramineae and was classified under the tribe Chlorideae by Kunth in 1829. It was transferred to Agrostideae by Trinius in 1840 and later to the tribe Paniceae by Bentham in 1881. Finally, Clapham, Tutin and Warburg (1952) placed the genus in the tribe Spartineae because of its spikelets containing one floret. According to a recent monograph by Mobberley (1956), the genus comprises sixteen species distributed in Europe, Africa, and North and South America.

The genus *Spartina* is represented by two species in California (Munz 1959). *Spartina foliosa* Trin. is a coastal species of salt marshes, most abundant in Humboldt and San Francisco Bays in northern California and along the coastal regions of Los Angeles and San Diego counties in southern California. This species extends to the Pacific coast of Baja California in Mexico. *Spartina gracilis* Trin. occurs in alkaline basins of Inyo and Mono Counties of California and extends from Mexico to the Mackenzie Territory of Alaska at the higher altitudes.

The present report deals with the morphology and ecological anatomy of *Spartina foliosa* which was collected by Dr. H. L. Mason from Petaluma River near Black Point growing in salt marshes with *Salicornia*. The root bearing rhizomes with a few young culms were

preserved in a fixative solution containing 70% Ethanol, Propionic acid Glacial Acetic acid for anatomical studies. Part of the living rhizomes were raised in the greenhouse as well as in outdoor conditions at the Botanical Garden of Mills College, Oakland. Material collected in dormant condition during November 1973 started to bloom in July 1974. Several herbarium sheets were prepared from dormant as well as from actively growing material for gross morphological observations. These are kept as voucher specimens in Mills College Herbarium located in the Life Sciences Building. The preserved leaves, culms, rhizomes and roots were sectioned with a Spencer Clinical microtome, stained with safranin and permanently mounted in microslides by using synthetic resins.

Gross morphology:

Spartina foliosa Trin. (syn: S. leiantha Benth., S. densiflora Brong. var. typica St. Y. subv. brongniertii St. Y. forma acuta St. Y.) is a perennial grass, vegetatively quite similar to the other members of the complex II (see p. 478 of Mobberley 1956) which includes S. alterniflora, S. longispica, S. maritima, S. Neyrautii and S. Townsendii. Cylindrical, erect culms are fleshy and glabrous, reaching a height of 1.5-2 m. The lower nodes of the culms produce adventitious roots which penetrate the muddy deposits in salt marshes. The fleshy, firm and white rhizomes are covered by loosely imbricate scales, 1-3 cm. long. Prominently ridged, fleshy rhizomes are 3-8 mm. thick and produce a large number of roots from their nodal regions anchoring the plants firmly in the muddy grounds of the intertidal zones. Leaf blades are flat or somewhat involute, tapering gradually into an acuminate tip. Blades are 15-40 cm. long, 8-12 mm. wide at the base. Sheath embracing the culm is 15-25 cm. long, prominently ridged on the surface, and pale yellow

or beige in color. Ligule consists of a ring of white delicate hairs, 1-3 mm. long. Panicle is 15-25 cm. long, bearing 4-10 slightly twisted spikes. Lower spikes are often enclosed within the uppermost sheath. Individual spikes are 3-8 cm. long, closely adpressed within each panicle. Likewise, the spikelets are adpressed toward the rachis which often extends beyond the terminal spikelet. The first glume is half as long as the second which is 8-25 mm. in length. Both glumes are usually curved, glabrous to sparingly pilose. The lemma is shorter than the second glume; palea is thin, papery, longer than the lemma, and two nerved. There are three stamens, 3-6 mm. long; the pistil has two plumose stigmas, the lodicules absent.

Anatomical observations:

So far as I know, there is no published data on the histology of the vegetative organs of Spartina foliosa. On the other hand, considerable anatomical and taxonomic information is available about Spartina townsendii which is regarded as an allopolyploid hybrid species between Spartina maritima (native to Europe and Africa) and Spartina alterniflora (native to the Atlantic coasts of North and South America).

A selected bibliography is listed at the end of this report. Although S. foliosa has no parental relation to S. townsendii, the literature on the anatomical structure of the latter served me as a guideline for comparing anatomical similarities and differences between these two species. Because of my unexpected illness, I did not have the opportunity to compare various races of Spartina foliosa from different levels of salt marshes around the Bay Area such as the low-low marsh, the high-low marsh, the low-high marsh.

Foliar Anatomy:

While describing the leaf anatomy of Spartina foliosa I shall follow the terminology of my earlier paper on Monocot leaves (Kasapligil 1961). The adaxial surface of the leaf blades are corrugated with ridges and furrows increasing the efficiency of the photosynthetic tissue. The number of ridges varies from 36 to 50 around the middle portion of the lamina. There is no midrib. The midportion of the blade is the thickest part as seen in transverse sections perpendicular to the leaf axis. The thickness of the blade at midportion varies from 336 microns to 576 microns as measured between the abaxial surface and the outer edge of the ridges along the adaxial surface. The ridges become smaller towards the blade margins, gradually merging into the wedge-shaped edge of the lamina.

Adaxial epidermal tissue:

The epidermal cell proper is characterized by the presence of the papillar extension of the outer cell walls. The cuticle layer of the outer walls of the upper epidermal cells is rather thin. Numerous, peg-like papillae which develop from the outer tangential walls of the epidermal cells proper prevent the wetting of leaf surfaces during the submersion of leaves at high tide. Both epidermal strips as well as the cleared whole mounts of leaves have been studied to determine the cell types of the epidermal tissue. In face view, epidermal cells proper appear elongated along the longitudinal leaf axis with typical undulate cell walls. These tabular epidermal cells are frequently interrupted by stomata and hydothodes and rarely intercepted by small cork cells with straight cell walls. The cork cells appear rectangular or square in face view and lack papillae.

The stomata are abundant along the lateral sides of the ridges facing the grooves, but they are totally absent along the flattened tips of the ridges facing the vascular bundles. The stomatal apparatus is of the sunken type associated with a prominent substomatal air space. In face view, the guard cells appear dumb-bell shaped which is characteristic of most of the grasses. Each pair of guard cells is accompanied by a pair of subsidiary cells which are also sunken below the epidermal layer. The guard cells are devoid of papillae, while the subsidiary cells are equipped with branched papillae extending from the outer walls. Most likely, such papillae entangle air bubbles and prevent the wetting of the stomatal apparatus during the submergence.

The hydathodes appear flask-shaped in the cross sections of the leaves. Again, the hydathodes are located along the flanks of the adaxial ridges while they are totally absent on the flattened tips of the ridges. The hydathodes consist of a large basal cell embedded within the outer mesophyll and a small cap cell intruding into the epidermal layer. The structure and function of the hydathodes is similar to those in Spartina townsendii described by Skelding and Winterbotham (1939). Both the basal and the cap cells are derived from an unequal periclinal division of a common initial cell of the young epidermis. Cap and basal cells contain dense cytoplasm as well as a nucleus. The walls of the swollen basal cells are heavily pitted where they come into contact with the adjacent chlorenchyma cells as well as the epidermal cells. The cap cells are devoid of pitting and their outer walls are slightly cutinized. The hydathode is a glandular apparatus which is responsible for the active secretion of sodium chloride. When the leaves are exposed to air, cubical salt crystals accumulate on the surface of hydathodes.

Finally, the epidermal cells lining the bottoms of the adaxial grooves are specialized as fulliform or motor cells responsible for the rolling and unrolling of the leaf blades. The bulliform epidermal cells are 2-3 times larger than the adjacent epidermal cells proper. They are characterized by thick cell walls without papillae and by the presence of prominent vacuoles with a clear watery content. Likewise, several underlying mesophyll parenchyma cells opposite the air lacuna are also specialized as bulliform cells, sharing the function of the epidermal bulliform cells. These cells also contain large vacuoles. Their peripheral cytoplasm, however, contains just a few chloroplasts.

Abaxial epidermal tissue:

Unlike the upper epidermis, the lower epidermis of the blade is heavily cutinized and lacks the papillar extensions. Unlike the abaxial epidermis of Spartina townsendii, the lower epidermal cells of S. foliosa are not undulate. Because of the heavy pitting on their radial walls they appear like a string of beads with many constrictions, as I observe in a face view of the cleared blades. The elongated epidermal cells proper alternate with small rectangular, rhomboid or triangular cork cells along the veins as well as in the areas between the veins. According to Sutherland and Eastwood (1916), the cork cells of Spartina townsendii are "saddle-shaped in the hollow of which the silica cell lies." In Spartina foliosa, the cork cells are accompanied by the silica cells quite infrequently. These small cells appear concave, biconcave or triangular in face view. The lumens of the silica cells are often filled completely by SiO_2. Occasionally the cork cells occur in pairs, in which case they may or may not be accompanied by a silica cell. The stomata and the hydathodes are sparingly distributed along the areas

between veins and never occur over the veins. The stomata of the abaxial epidermis are considerably larger (37-40 microns in length) than the stomata of the adaxial epidermis (24-30 microns long). The structure and function of the hydathodes are similar to those described for the abaxial epidermis.

Mesophyll:

The outermost two or three cell layers of the mesophyll facing the vascular bundles consist of highly lignified sclerenchyma fibers with reduced lumens. The sclerenchyma tissue extends across the flattened tips of the adaxial ridges associating intimately with the adjacent upper epidermis. On the lower side of the leaf blade, the sclerenchyma fibers form alternating large and small patches of tissues opposite alternating large and small veins respectively. Again those clusters of sclerenchyma fibers are closely associated with the subjacent abaxial epidermal cells. Since the inner tangential walls of the epidermal cells in contact with sclerenchyma are lignified and firmly cemented to the fiber cells, it was practically impossible to obtain clean strips of epidermal tissue. In every attempt of peeling epidermis, the patches of sclerenchyma were pulled out together. The blade margins are occupied by several layers of sclerenchyma fibers. Needless to say, the sclerenchyma tissue provides excellent support and rigidity to the leaf blades during the rolled or unrolled states.

The chlorenchyma consists of one or two layers of irregularly shaped parenchymatous cells with prominent intercellular spaces along the flanks of the adaxial ridges. In the young leaves, this tissue extends all the way from the bottoms of the furrows to the abaxial epidermis. Upon the aging of the leaf, however, chlorenchyma tissue between the vascular

bundles disintegrates, leaving prominent air lacunae behind. The remnants of the collapsed cell material around the air cavities suggest the lysigenous origin of the lacunae. As in the S. townsendii leaves, these air passages continue all the way from the blade to the sheath although they may be interrupted by diaphragms. However, the continuity of the aerenchyma is not disrupted since the spongy parenchyma cells forming the diaphragm have plenty air spaces between.

The lacunae are oval or elliptical in outline as seen in transverse leaf sections. In the material I studied, their width varies between 80 and 200 microns.

The collateral vascular bundles occupy a central position between the tips of adaxial ridges and abaxial epidermis. Orinarily large and small vascular bundles alternate with each other. The large vascular bundles are characterized by the presence of conspicuous tracheary elements in their metaxylem. Their phloem consists of thin walled, compactly arranged elements. Furthermore, the large bundles are surrounded by a sclerenchyma sheath formed by the xylem and phloem fibers. In the cross-sections of the blades, the width of the large vascular bundles including the sclerenchymatous sheath ranges from 96 microns to 128 microns, while their length varies from 128 microns to 160 microns. Small vascular bundles lack a sclerenchymatous sheath and are simply surrounded by thin walled border parenchyma with conspicuous vacuoles. The small vascular bundles are 1/2 - 1/3 of the size of the large bundles when seen in transverse sections. The large parenchyma cells of the bundle sheath as well as of the bundle sheath extensions are characterized by the presence of crescent-shaped mucilagenous substances, constantly situated near their external walls. Bundle sheath

and bundle sheath extensions in *Spartina townsendii* are designated as a "water storing envelope" by Sutherland and Eastwood who do not mention the mucilagenous clumps in them. Microchemical tests are required to understand the actual chemical nature of the mucilagenous clumps as well as the other particulate contents of the bundle sheath cells in *Spartina foliosa*.

Cross anastomoses between the parallel running neighbor veins seem to be rather rare or infrequent. According to my measurements through the whole mounts of cleared blade portions, the distance between two subsequent cross-connecting veins ranges from 640 microns to 2080 microns. Cross connecting veins are either perpendicular or oblique or sigmoid type with regard to their position in relation to parallel veins when observed in face view of the blades.

The foliar trichomes are ordinarily deciduous; but a few unicellular hairs remain attached to the blade margins at the mature stage of the foliage. These awl-shaped trichomes develop from the epidermal cells of the blade margins. Their basal, semicylindrical portions are marked with slit like simple pits along the area of contact with the subjacent cells. The tapering free ends of the trichomes are 130-150 microns long and pointed toward the blade apex.

Anatomy of the culm:

The internodal and the nodal portions of the culm have been examined through transverse as well as longitudinal sections. The internodal part of the culm is characterized by the presence of two sets of prominent air spaces, i.e., outer cortical lacunae and a large central pith canal. The tissues of the culm at the internodal region are summarized as follows:

Epidermis is a simple tissue composed of epidermal cells proper extending longitudinally parallel to the culm axis, often interrupted by cork cells and less frequently by the cork and silica cells associated closely. Epidermal cells have minutely wavy walls which are densely pitted along their radial walls. The cork cells are rectangular or somewhat concave. No stomata, trichomes or hydathodes have been observed in epidermal strips obtained from fully mature culms. Outer tangential walls of the epidermal cells are heavily cutinized.

Cortical parenchyma tissue consists of 12-20 layers of thin walled cells with conspicuous intercellular spaces. Upon the growth of culms, patches of cortical parenchyma cells between the outermost vascular bundles disintegrate and give rise to cortical lacunae. The remnants of the wall material of collapsed parenchyma cells can be seen lined up all around the peripheries of the cortical lacunae. The number of lacunae are equal to the number of outermost vascular bundles. In the cross sections I studied, I counted 18-20 lacunae corresponding to 18 to 20 outer vascular bundles. The inner region of the ground parenchyma where the vascular bundles are situated is rather a compact tissue since the intercellular spaces are extremely small. Actually the ground parenchyma of the inner cortex consists of elongated polygonal cells containing starch grains.

The large pith cavity in the center extends throughout the internodal region being interrupted by nodal diaphragms. As in the cortical lacunae, the peripheral limit of the pith cavity is lined with layers of wall materials left over by the collapsed pith parenchyma cells.

The collateral vascular bundles, each enclosed within a sclerenchyma sheath, are arranged in three distinct rings. The outermost vascular bundles adjacent to cortical lacunae are cauline bundles which extend vertically throughout the culm. In Spartina foliosa stem, I have not seen a layer of subepidermal bundles, although the presence of an extra circle of vascular bundles was described for S. townsendii by Lauder-Thomson (1933). The second and third rings of vascular bundles supply the leaves attached to upper nodes. These are leaf traces.

The nodal anatomy differs considerably from the anatomy of the internodal region. First of all, epidermis as well as the underlying six to seven layers of cells are strongly lignified forming a continuous cylinder of sclerenchyma all around the nodal region. The outer sclerenchymatous cylinder is followed by a cortical cylinder composed of isodiametric cells containing starch grains. The cortical parenchyma exhibits conspicuous intercellular spaces. Adjacent to the parenchymatous cortex there is another thick cylinder of sclerenchyma tissue delimiting the pith parenchyma and the vascular bundles dispersed in it. These two sclerenchymatous rings provide an enormous mechanical support to the nodal regions. The nodal diaphragm as well as the diaphragms separating the cortical lacunae at the nodal level consist of small isodiametric cells containing starch grains. The vascular bundles don't seem to form regular circles in the nodal region. The collateral bundles of different sizes are scattered throughout the central diaphragm and quite often these bundles are interconnected by transverse bundles. The vascular bundles are enclosed within a bundle sheath containing starch grains. Apparently, the transverse bundles running on the same plane as the nodal diaphragm are mainly responsible for interconnecting the leaf

traces. The origin and function of the transverse vascular bundles deserve further investigation.

Rhizome anatomy:

Rhizomes basically manifest the same topography of tissues as I discussed under the previous heading of the culm anatomy. Instead of sheathing leaf bases, the rhizomes are enclosed by more or less imbricating scales devoid of chlorenchyma. These underground stems also exhibit nodal and internodal regions with more pronounced cortical lacunae and pith cavities in the latter regions. Unlike the culm, however, the air passages of lacunae and the central pith canal are interrupted by thin diaphragms at the nodal regions. Furthermore, the development of lateral roots are more abundant than in the lower nodal regions of the culms. Both the cortical and pith parenchyma tissues of the rhizomes are practically filled by starch grains. Simple and compound starch grains occur in the same cells.

According to Sutherland and Eastwood (1916), the rhizomes of Spartina townsendii are fleshy and flaccid. As I pointed out earlier, the rhizomes of Spartina foliosa are firm and rigid since they contain well-developed sclerenchymatous tissues of many layers thick.

Root anatomy:

As in Spartina townsendii, two kinds of roots such as thick, unbranched anchorage roots and thinner, profusely branched absorption roots are easily distinguishable in S. foliosa. The anchorage roots penetrate into deeper layers of the muddy ground while the absorption roots ramify profusely forming an intricate mat in the upper layers of mud flats. Although both kinds of roots show a positive geotropic response, quite often the anchorage roots follow a negative geotropic

pattern of growth which possibly represents an adaptation to an efficient aeration during low tide. With the exception of their apical meristematic regions, both types of roots have numerous cortical lacunae extending radially from outer regions of endodermis to the inner edge of the exodermal layers. Since I did not prepare serial paraffin sections, I am not in a position to compare the continuity of the air passages of the adventitious roots with those found in the culms and rhizomes.

Young adventitious roots, before emerging through the outer cortical regions of the rhizomes, exhibit a very orderly stratification of tissues. At the early stage of development, the cortical parenchyma is arranged in regularly radial rows. In the anchorage roots, the cortical tissue becomes quite bulky while in the absorption roots, the cortex remains rather scanty. The vascular tissues of the adventitious roots are supplied by the outermost vascular bundles of the rhizome nodes. The continuity of the vascular traces "entering" the adventitious roots is quite evident in the transverse sections I examined.

Mature adventitious roots exhibit a radial arrangement of the stelar tissue with ten to twelve protoxylem poles in contact with the pericycle. The tracheary elements at the protoxylem poles are thick walled, while the metaxylem vessels are relatively thin walled although both of these elements are lignified. The central portion of the stele is occupied by a lignified pith. Exodermis consists of three to four layers of cortical parenchyma cells which are lignified uniformly and arranged compactly without intercellular spaces.

In conclusion, the ecological anatomy of Spartina foliosa is quite similar to that of S. townsendii while these two taxa differ from each other in certain details as pointed out under different headings.

Aug. 30, 1974

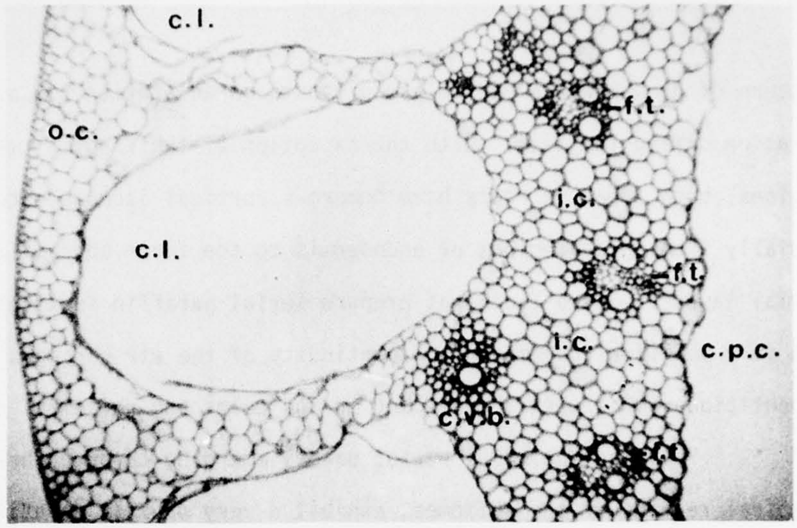

Fig. 1 - Transverse section of the aerial culm of Spartina foliosa, showing outer cortex (o.c.), inner cortex (i.c.), cortical lacuna (c.l.), cauline vascular bundle (c.v.b.), foliar traces (f.t.) and central path cavity (c.p.c.).

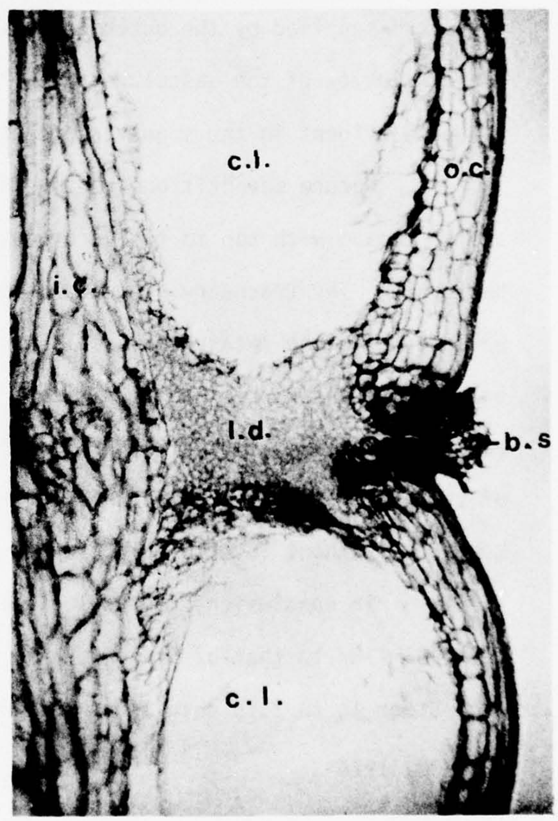

Fig. 2. - Longitudinal section of the culm of Spartina foliosa showing: two cortical lacunae (c.l.), outer cortex (o.c.), a portion of the inner cortex (i.c.), lacunar diaphragm at the node (l.d.), and base of sheath attached to the node (b.s.).

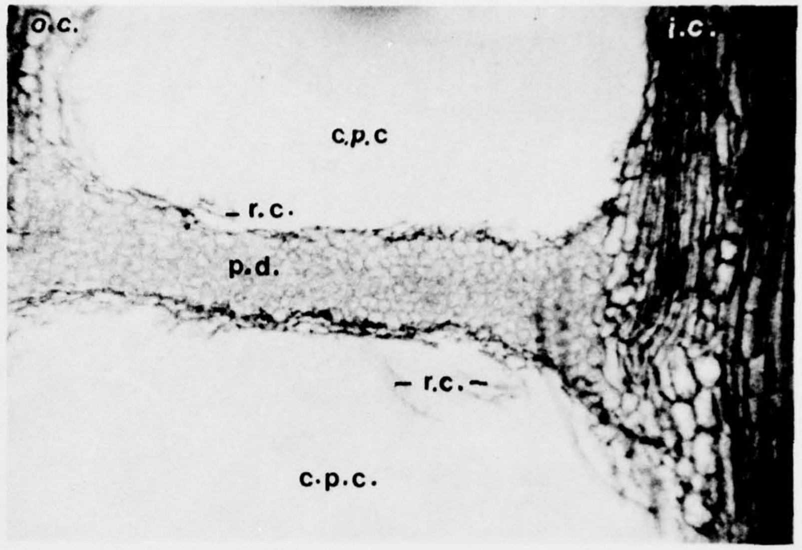

Fig. 3 - Longitudinal section of the culm of Spartina foliosa showing central pith cavities (c.p.d.) divided by pith diaphragm (p.d.) at the node, remnants of the collapsed cell walls (r.c.), inner cortex (i.c.) and outer cortex (o.c.).

Fig. 4. - Longitudinal section of the culm at the node showing the vertical air passages (a.p.) interrupted by nodal diaphragms (n.d.). Note the superimposed vessel members (v.m.) in the vascular bundle to the right.

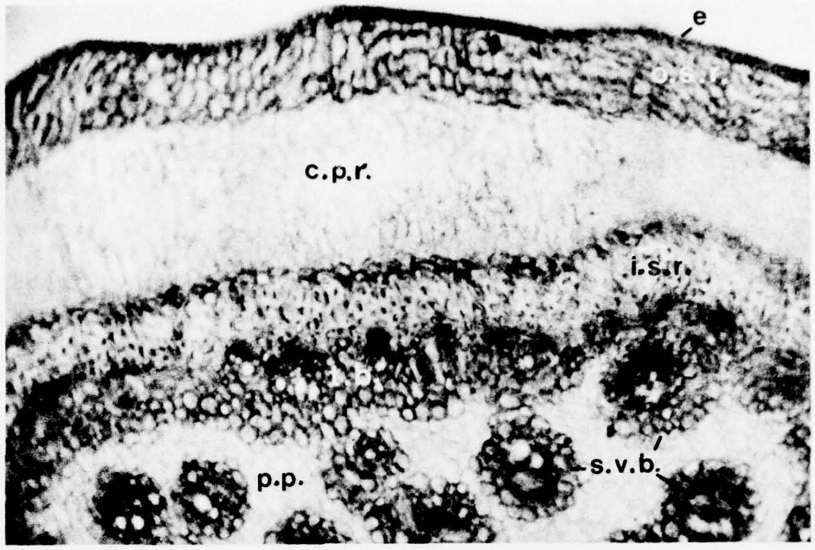

Fig. 5 - Transverse section of the rhizome at the nodal region showing epidermis (e), outer sclerenchyma ring (o.s.r.), inner sclerenchyma ring (i.s.r.), cortical parenchyma ring (c.p.r.), scattered vascular bundles (s.v.b.) and transverse bundles (t.b.) and pith parenchyma (p.p.).

Fig. 6 - Transverse section through the nodal region of Spartina foliosa rhizome showing the adventitious roots (a.r.), scattered vascular bundles (s.v.b.) of the rhizome and the vascular trace (v.t.) supplying a young root.

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APPENDIX D

CHROMOSOME NUMBERS IN GROWTH FORMS OF SPARTINA FOLIOSA, TRIN.

by

Professor Dennis R. Parnell

INTRODUCTION

Two growth forms of Spartina foliosa, Trin., California Cord-grass, are found growing in the San Francisco Bay (Mason 1973). The habitat for each growth form is the same throughout its range.

The tall form grows characteristically the furthest seaward in the marsh and along creekbanks. The short form grows landward in the emergent zone at the upper limits of the range of Spartina. The question has arisen whether or not these two growth forms represent chromosomal races. The purpose of this study is to answer this question.

PROCEDURES

Collection of specimens--Specimens for the study were collected from the Marine Research Center nursery at Pt. San Pablo and from a marsh north of and adjacent to the Dumbarton Bridge. Specimens from Pt. San Pablo were fixed at the Center immediately upon being removed from their pots. The tall growth form specimens had been grown from seed and the short growth form from cuttings, both of which had been collected the previous year. Only healthy plants were used and the specimens were carefully washed under running water to remove any excess debris. Young, white, clean root tips were clipped directly behind the meristematic region. As many root tips as possible were collected from one plant.

Plants collected from the Dumbarton Bridge marsh were dug up in large clumps of rhizomes, roots, and mud, and placed in plastic trays

for transport to the California State University, Hayward, greenhouse. There, they were placed in aquaria and submerged in water up to the level of the mudline. Individual plants were periodically removed and root tips were collected in the manner described above.

Fixing--Root tips were placed immediately in small vials containing oxyquiniline. The amount of time in which the roots remained in the oxyquiniline was initially 3-1/2 hours, but was increased to seven hours to insure both the maximum contraction of the chromosomes and inhibition of the mitotic spindle. The roots were then transferred to the fixative (1 part glacial acetic acid and 3 parts absolute alcohol) to reduce the staining of the cytoplasm. The roots remained in the fixative until they were stained. If the period of time between fixing and staining was more than two days the roots were transferred to a 95% alcohol solution. Generally, specimens were observed within two days following fixing.

Staining. Immediately prior to staining, the root tips were hydrolysed in N.HCl to improve the selectivity of staining. The roots were then stained using the Feulgen nuclear reaction technique (Johansen, 1940).

Preparation of the slides and observation. Staining was complete within three hours, when the very small meristematic region of the root tip appeared densely purple. This portion of each root tip was clipped off and placed on a slide under a cover slip and squashed according to the root squash technique (Darlington, 1960). Each slide was scanned systematically for mitotic chromosomes. At this point it became obvious that, although mitotic chromosomes could be seen, there would be difficulty in obtaining a slide suitable for photography. The

cells remained tightly bound to each other by the middle lamella making it difficult to separate the cells and to spread the chromosomes. This technique was refined by using pectinase, an enzyme that breaks down the middle lamella between adjacent cells. Although this improved somewhat the spread of the cells, it was obvious that it still remained a difficult task to produce a slide suitable for photography. The identical problem has been encountered in the past by other investigators of *Spartina* cytology (e.g., Marchant, 1963, and personal communication).

Several hundred observations were made. Photomicrography was done on a Zeiss phase contrast microscope at a magnification of 8,000x. Drawings were made from the slides to facilitate the study of the photographs. This was necessary because of the difficulty encountered in obtaining slides with all of the chromosomes on the same plane.

CONCLUSION

The diploid chromosome number for both forms of *Spartina foliosa* was determined to be 2N=60 (figures 1 and 2). The previously published chromosome number for the species, 2N=56 (Church, 1940), appears to be in error. There was no evidence that the two forms of *Spartina foliosa* represent different polyploid races.

Additional research will be necessary to determine if the variation in growth form is under genetic or environmental control.

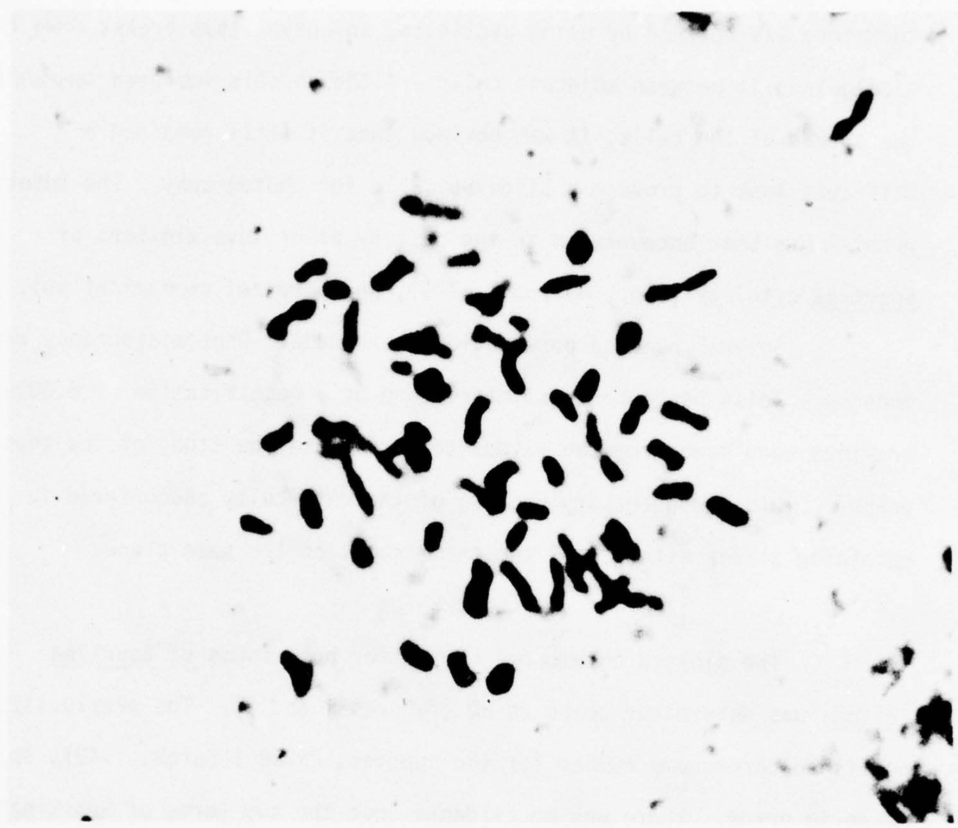

Figure 1. Mitotic chromosomes of Spartina foliosa, Trin., tall growth form 2N=60 (8000x).

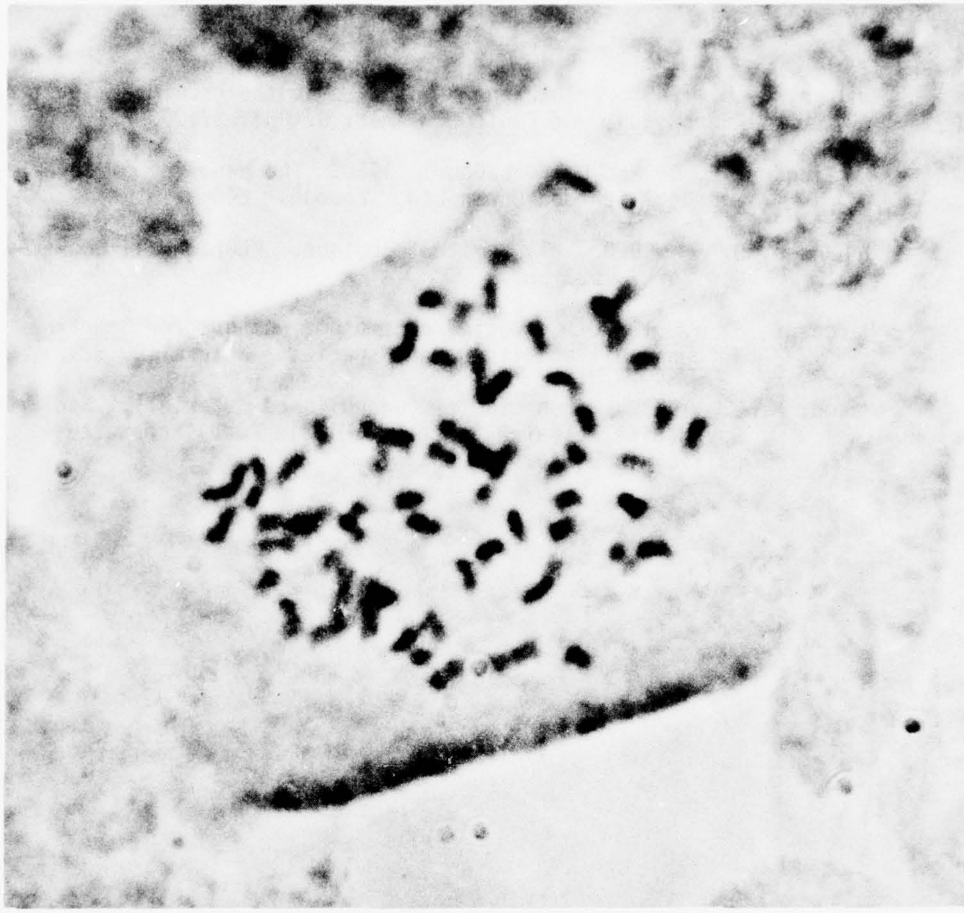

Figure 2. Mitotic chromosomes of _Spartina_ _foliosa_, Trin., short growth form 2N=60. (8000x).

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APPENDIX E

OXYGEN TRANSPORT IN SPARTINA FOLIOSA TRIN.

by

Geoffrey Wong

Abstract Atlantic species of *Spartina* are known to transport oxygen gas from the air through plant tissue to the root system and its subsurface environment. This study presents experimental evidence that the Pacific species, *Spartina foliosa* Trin. is likewise able to transport oxygen downward into the soil. This process may account largely for the presence of the plant in a relatively anaerobic subsurface environment.

I. INTRODUCTION

Adequate oxygen supply is a basic physiological requirement for normal respiration of a plant. To restrict oxygen supply is to alter biochemical equilibria, rates of assimulation of nutrients, and, indeed, rates of energy transfer throughout the plant (Waisel 1974). In marshland, oxygen availability frequently is a limiting factor to normal growth and distribution of certain halophytes. But these plants are known to be tolerant to short periods of anaerobioses and some species have been found to prefer such conditions. Some species of *Spartina* invade highly anaerobic marshlands by vegetative processes, and are known to provide their roots with oxygen from aerial tissues of the plant.

Disregarding the possible toxic effects of particular substances that may occur in marsh habitats dominated by anaerobic conditions, there is still some question as to how certain plants grow

normally in anaerobic soil. It is well known that a number of halophytes are able to grow under low oxygen conditions. It has been demonstrated that Spartina townsendii Groves and Spartina alterniflora Loisel have large air ducts through which oxygen moves downward from, and through the aerial tissues of the plant to the subsurface rhizomes and roots (Sutherland and Eastwood, 1916). In fact, according to van Raalte (1940) oxygen may in rice plants leak out of the roots to the ambient environment. It has been assumed that this oxidative process is responsible for the soil immediately around cordgrass roots being reddish in color from iron oxides while nearly surrounded by muds that are black from sulphide origin.

Dredge material may constitute a particularly rigorous environment for the survival and growth of the Western cordgrass, S. foliosa. This species has not been as extensively studied as the Atlantic coast species of the United States and Europe. Accordingly, morphological studies, reported in Appendix C by Professor Baki Kasapligil, were undertaken to demonstrate the nature of the downward oxygen transport in S. foliosa Trin. The redox potential study reported in Appendix A by Messrs. Charles R. Pride and Donald E. Lingle provides some evidence of the possible release of oxygen to the surrounding soil layers.

This preliminary physiology study was initiated to measure the oxygen levels around the root system of this halophyte, and perhaps provide further evidence of the extent of oxygen liberation from the plant.

II. METHODS

A series of tests were devised to demonstrate that S. foliosa does release oxygen to the area surrounding the roots. Spartina plants

which had been growing in sand, chosen so that all specimens were approximately the same size, were washed free of the sand substrate. The plants were allowed to recover from the transfer shock for two weeks by placing them in a weak nutrient solution and under fluorescent lights near a window.

Eight different tests were prepared. The basic method was to place each specimen into a 250 ml Erlenmeyer flask of water so that both the soil line on the plant and the water level were at the neck of the flask. Warm but still liquid paraffin was poured into the neck in order to seal the root portion into the flask. After incubation at room temperature for 2 days, each plant was removed and the flasks resealed immediately. Oxygen concentrations in the water samples were then determined by the Winkler ozide modification method.

Half of the eight tests started with water saturated with oxygen, and a parallel group started with completely degassed water. Saturated water was prepared by shaking distilled water in the presence of air. Degassed water was made by boiling distilled water for 15 minutes. The hot water was transferred to the flasks before cooling.

In order that the final concentrations of oxygen found in the water surrounding the roots of an intact plant have meaning, it was necessary to determine the background levels of oxygen due to three other parameters. The results of these controls enable one to interpret the data properly.

One must know what the oxygen level would have been had the roots <u>not</u> had access to the atmosphere via the aerial portion of the plant. Experimentally, this was found by severing a plant at the soil

line and sealing the root portion into the flask. These tests are labeled "roots only" in table 1.

In order to learn the magnitude of contamination of the water samples by atmospheric oxygen, two pairs of tests were carried out. A water blank carried through all the steps except with the plants would indicate a starting oxygen level.

The amount of oxygen introduced by placing the plant roots into the flask and then removing them was also measured. This "dipping blank" was made after the incubation period to avoid spurious effects from incubation of contaminants. One would not expect any significant change in the aerated water since it is already saturated. However, a small increase in oxygen level might be observed in the degassed water. This would be due mainly to oxygen dissolved in fluids adhering to the surface of the roots.

III. OBJECTIVE

The purpose of this experiment is to demonstrate that roots of cordgrass plants of the species S. foliosa Trin. are able to exude oxygen that originates in the aerial portions of the plants.

IV. RESULTS AND DISCUSSIONS

The results of the tests, summarized in table 1, show that S. foliosa does conduct a certain amount of oxygen to the medium surrounding its roots (3) and (4). It is apparent that the normal respiration activity of the root tissue is sufficient to lower within 2 days the concentration of oxygen below the limit of detectability of the assay method (3) and (7). Therefore, the small amount of oxygen introduced by dipping is inconsequential (5) and (6).

Those flasks which had whole plants sealed into them are seen to contain a significant level of oxygen. This indicates that the Spartina plant can supply not only enough oxygen to fulfill the needs of its roots, but in addition it can supply a certain amount to the water surrounding the roots. The excess oxygen is recorded as a measurable concentration in the solution.

Sutherland and Eastwood (1916) in their study of the anatomy of S. townsendii show the presence of a great amount of aerenchyma tissue in the roots, rhizomes, stems and leaves. This spongy, air-filled tissue is undoubtedly the major conducting pathway for gaseous oxygen from the atmosphere to the roots. Diffusion through a liquid path would be much too slow to provide sufficient oxygen. Mass flow, of plant fluids containing dissolved oxygen through the plants into the roots could conceivably sustain the root tissue, but this hypothesis also must be discarded in light of the report of Armstrong (1964). From this paper it is seen that the response to the application of oxygen to a plant previously starved of the gas for one and a half hours was too rapid, less than two minutes, to be accounted for by mass flow. Mass flow would also be too slow to provide the large excess quantities of oxygen reported in several instances.

Rates of diffusion of oxygen and carbon dioxide in S. alterniflora were measured by Teal and Kanwisher (1966) using a double-chambered measuring system. The air spaces were documented as being the primary gas transport system in the plant and were demonstrated as being capable of providing in excess all the oxygen needed by the roots. Again, it may be concluded that the success which Spartina enjoys in colonizing tidal

mud flats can be attributed largely to its highly developed aerenchyma system, which enables it to live in anaerobic substrates.

Table 1: Concentration of O_2 in solution

	ppm O_2*
Aerated water	
(1) water blank	7.6
(2) dipping blank	7.6
(3) roots only	0.0
(4) whole plant	1.6
Degassed water	
(5) water blank	0.9
(6) dipping blank	1.4
(7) roots only	0.0
(8) whole plant	-**

*Average of two values; estimated uncertainties about ±0.1 ppm.

**No data.

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APPENDIX F

RECORDS ON VOLUNTEERS IN THE EXPERIMENTAL CONTROL AREAS

As a control for the 66 treated experimental plots, 5 replicate, plant-free plots in the *Spartina* area were selected at random for observational purposes and fertilized. Five additional replicates were unfertilized. Three replicates of fertilized and of unfertilized control plots in the *Salicornia* area were likewise chosen at random. Records taken in August and October for these control, 25 meter square, plots are: total number and kinds of plants, height, and mean number of stems. In addition to *Spartina foliosa* Trin., two species of *Salicornia* were observed--*S. pacifica* and *S. rubra* A. Nels.--at both intertidal levels (tables 1 and 2).

In August, 5 *Spartina foliosa* Trin. volunteers were observed in one of the 7-foot (2.1 meter) level replicate plots and one in another of the fertilized plots. By October, none of the 5 remained while the remaining one had more than doubled its height and number of stems (August, 8.3 cm. with 2 stems; October, 19.5 cm. with 5 stems). Other plants observed in these plots were *Salicornia pacifica* Standl. and *S. rubra* A. Nels.

The average number of *S. pacifica* Standl. seedlings per plot observed in August was 6.2 and in October, 7.2 (table 1, fert.).

Table 1. Spartina Area Control Plots at Alameda Creek

		AUGUST			OCTOBER		
Repli-cates	Mean Measurement	Spartina foliosa	S. pacifica	S rubra	Spartina foliosa	S pacifica	S rubra
Fert.	Total Number	-	4	-	-	10	-
1	Height	-	13.6	-	-	24.47	-
	Stem Number	-	9.25	-	-	9.9	-
	Total Number	1	9	1	1	6	-
2	Height	8.3	12.72	17.2	19.5	27.67	-
	Stem Number	2	5.78	7	5	14.7	-
	Total Number	-	10	2	-	5	2
3	Height	-	17.84	9.7	-	32.3	17.5
	Stem Number	-	17	1.0	-	43.6	22.5
	Total Number	5	8	4	-	7	-
4	Height	18.92	8.59	16.8	-	24.36	-
	Stem Number	2.6	2	6.25	-	11.71	-
	Total Number	-	-	8	-	8	1
5	Height	-	-	15.64	-	20.53	19.0
	Stem Number	-	-	5.75	-	7.13	22
Unfert.	Total Number	3	-	-	-	9	-
1	Height	24.83	-	-	-	24.93	-
	Stem Number	23	-	-	-	20.22	-
	Total Number	-	-	-	-	-	-
2	Height	-	-	-	-	-	-
	Stem Number	-	-	-	-	-	-
	Total Number	-	-	10	-	7	1
3	Height	-	-	15.51	-	25.96	19.2
	Stem Number	-	-	4.8	-	17.71	14
	Total Number	1	-	17	4	9	1
4	Height	24.5	-	17.56	8.43	30.73	18.5
	Stem Number	5	-	6.59	2.25	15.56	9
	Total Number	-	-	1	-	-	1
5	Height	-	-	17.8	-	-	23.5
	Stem Number	-	-	5	-	-	26

Table 2. Salicornia Area Control Plots at Alameda Creek

Replicates	Mean Measurement	AUGUST Salicornia pacifica	AUGUST S Rubra	AUGUST Spartina foliosa	OCTOBER Salicornia pacifica	OCTOBER S rubra	OCTOBER Spartina foliosa
Fert.	Total Number	3	-	-	1	-	-
1	Height	23.13	-	-	40	1	1
	Stem Number	11	-	-	75	-	-
	Total Number	5	-	-	5	-	-
2	Height	29	-	-	33.68	-	-
	Stem Number	19.6	-	-	26.6	-	-
	Total Number	-	-	-	-	-	-
3	Height	-	-	-	-	-	-
	Stem Number	-	-	-	-	-	-
Unfert.	Total Number	1	-	-	-	-	-
1	Height	8.5	-	-	-	-	-
	Stem Number	1	-	-	-	-	-
	Total Number	-	-	-	-	1	-
2	Height	-	-	-	-	16	-
	Stem Number	-	-	-	-	21	-
	Total Number	1	-	-	-	1	-
3	Height	8.6	-	-	-	23	-
	Stem Number	3	-	-	-	15	-

APPENDIX G

TABLES OF EXPERIMENTAL PLANT GROWTH DATA

Survival and Growth of Test Plantings

Table 1. Showing mean percent survival, during the May-October period, of the four growth forms of <u>Spartina foliosa</u> Trin. planted in fertilized (F) and unfertilized (U) plots in mid-May, 1974, at the Alameda Creek Experimental Area. The means of each of the five plot means, and the corresponding coefficients of variation are given.

Months	Treatment	Planting Stock	Plot 1 $\bar{x}$	Plot 1 C.V.	Plot 2 $\bar{x}$	Plot 2 C.V.	Plot 3 $\bar{x}$	Plot 3 C.V.	Plot 4 $\bar{x}$	Plot 4 C.V.	Plot 5 $\bar{x}$	Plot 5 C.V.	Mean of Plot Means	C.V. %
5	F	Seeds												
		Seedlings												
		Rooted Cuttings, R.												
		Rooted Cuttings, D.												
		Robust Plugs												
	U	Seeds	–										–	
		Seedlings	100										100	
		Rooted Cuttings, R.	100										100	
		Rooted Cuttings, D.	100										100	
		Robust Plugs	100										100	
8	F	Seeds	100		100		100		100		–		100	
		Seedlings	44		100		68		44		48		60.8	
		Rooted Cuttings, R	44		60		40		20		28		38.4	
		Rooted Cuttings, D.	88		84		96		72		68		81.6	
		Robust Plugs	92		100		96		92		88		93.6	
	U	Seeds	100		100		100		100		–		100	
		Seedlings	64		68		56		64		40		58.4	
		Rooted Cuttings, R	8		24		36		36		24		25.6	
		Rooted Cuttings, D	72		60		76		72		40		64.0	
		Robust Plugs	60		88		92		98		76		82.4	
10	F	Seeds	250		77		24		50		–		100.25	
		Seedlings	36		84		64		44		36		52.8	
		Rooted Cuttings, R	44		80		24		16		12		35.2	
		Rooted Cuttings, D.	60		76		92		72		64		72.8	
		Robust Plugs	96		84		72		88		76		83.2	
	U	Seeds	89		107		78		52		–		81.5	
		Seedlings	60		60		68		60		28		55.2	
		Rooted Cuttings, R.	4		16		44		28		12		20.8	
		Rooted Cuttings, D.	72		68		92		64		36		68.4	
		Robust Plugs	52		92		92		84		64		76.8	

Survival and Growth of Test Plantings

Table 2. Showing the mean numbers of stems per plot of the five growth forms of Spartina foliosa Trin. planted in fertilized (F) and unfertilized (U) plots in mid-May, 1974, at the Alameda Creek Experimental Area. The means of each of the five plot means, and the corresponding coefficients of variation are given.

Months	Treatment	Planting Stock	Plot 1 $\bar{x}$	Plot 1 C.V.	Plot 2 $\bar{x}$	Plot 2 C.V.	Plot 3 $\bar{x}$	Plot 3 C.V.	Plot 4 $\bar{x}$	Plot 4 C.V.	Plot 5 $\bar{x}$	Plot 5 C.V.	Mean of Plot Means	C.V. %
5	F	Seeds												
		Seedlings												
		Rooted Cuttings, R.												
		Rooted Cuttings, D.												
		Robust Plugs												
	U	Seeds												
		Seedlings	1.0	0									1.0	0
		Rooted Cuttings, R.	1.3	52.3									1.3	52.3
		Rooted Cuttings, D.	2.1	35.2									2.1	35.2
		Robust Plugs	5.2	29.8									5.2	29.8
8	F	Seeds	1.5	47.3	1.0	0	2.3	20.9	1.0	0	—	—	1.4	17.0
		Seedlings	2.5	47.4	3.6	76.4	4.1	33.7	2.9	67.7	2.0	42.5	3.0	53.6
		Rooted Cuttings, R	1.6	62.8	2.8	41.1	2.6	51.4	1.4	63.6	1.0	0	1.9	43.9
		Rooted Cuttings, D	2.5	58.5	4.5	48.2	3.7	61.1	2.7	60.3	2.3	52.8	3.1	56.2
		Robust Plugs	4.7	61.1	4.2	70.8	4.9	47.3	3.9	56.3	4.0	62.2	4.3	59.6
	U	Seeds	1.0	0	1.0	0	1.6	43.7	1.0	0	—	—	1.1	10.9
		Seedlings	2.8	54.1	3.5	55.0	2.9	67.6	2.2	53.4	2.1	57.1	2.7	57.5
		Rooted Cuttings, R	1.0	0	1.8	63.9	2.2	66.7	1.7	59.9	1.8	63.9	1.7	50.9
		Rooted Cuttings, D	2.6	44.9	3.1	49.8	2.7	71.9	1.8	56.2	1.7	62.3	2.4	52.0
		Robust Plugs	3.9	46.6	4.9	53.4	4.7	66.2	4.1	65.6	2.9	58.3	4.1	58.0
10	F	Seeds	2.6	70.0	2.3	66.8	5.0	36.0	3.2	34.3	—	—	3.3	53.0
		Seedlings	8.2	49.8	7.0	58.1	7.2	56.8	10.0	84.8	7.6	124.9	8.0	75.5
		Rooted Cuttings, R	2.6	64.0	5.9	58.5	4.5	54.0	3.2	46.1	2.0	50.0	3.7	54.5
		Rooted Cuttings, D.	4.3	56.3	8.4	40.3	6.6	83.9	4.6	70.3	5.4	99.6	5.9	70.1
		Robust Plugs	6.0	74.7	6.5	87.0	8.3	55.0	6.3	78.0	7.4	69.7	6.9	72.9
	U	Seeds	1.9	61.5	2.0	55.3	1.4	54.5	1.6	49.1	—	—	1.7	55.1
		Seedlings	4.6	60.2	6.4	38.4	6.0	81.7	6.6	85.1	6.6	47.2	6.1	62.5
		Rooted Cuttings, R.	2.0	0	3.7	73.3	3.3	51.4	3.9	55.0	4.0	90.2	3.4	54.0
		Rooted Cuttings, D.	4.6	47.7	5.5	45.7	6.5	58.3	4.7	63.1	5.0	36.0	5.3	50.2
		Robust Plugs	5.7	54.8	6.4	52.2	6.3	53.3	6.2	51.1	6.2	59.1	6.3	54.1

Survival and Growth of Test Plantings

Table 3. Showing mean growth in height per plot of five growth forms of Spartina foliosa Trin. planted in fertilized (F) and unfertilized (U) plots in mid-May, 1974, at the Alameda Creek Experimental Area. The means of each of the five plot means, and the corresponding coefficients of variation are given.

Months	Treatment	Planting Stock	Plots 1 $\bar{x}$	1 C.V.	2 $\bar{x}$	2 C.V.	3 $\bar{x}$	3 C.V.	4 $\bar{x}$	4 C.V.	5 $\bar{x}$	5 C.V.	Mean of Plot Means	C.V. %
5	F	Seeds												
		Seedlings												
		Rooted Cuttings, R.												
		Rooted Cuttings, D.												
		Robust Plugs												
	U	Seeds												
		Seedlings	8.4	40.7									8.4	40.7
		Rooted Cuttings, R.	37.9	28.4									37.9	28.4
		Rooted Cuttings, D.	20.3	28.5									20.3	28.5
		Robust Plugs	55.3	12.8									55.3	12.8
8	F	Seeds	11.6	17.1	8.5	26.2	9.9	18.0	7.9	30.8	–	–	9.4	23.0
		Seedlings	13.8	40.1	16.0	36.4	17.7	23.3	13.7	29.5	11.2	30.7	14.5	32.0
		Rooted Cuttings, R	14.7	64.8	17.3	39.6	17.4	46.3	17.8	33.6	10.6	55.6	16.6	48.0
		Rooted Cuttings, D	15.9	30.7	16.4	53.0	17.0	43.2	14.7	40.4	13.4	36.4	15.5	40.7
		Robust Plugs	12.9	37.4	21.9	28.3	27.8	32.0	21.3	53.2	21.3	48.4	21.0	39.9
	U	Seeds	7.8	31.7	7.1	35.4	12.2	14.0	9.7	24.4	–	–	9.2	26.4
		Seedlings	15.0	38.9	15.6	40.4	12.4	36.8	13.5	36.8	12.8	30.2	13.9	36.6
		Rooted Cuttings, R	15.3	35.5	16.3	28.5	16.4	52.6	10.5	60.6	17.4	68.3	15.2	49.1
		Rooted Cuttings, D	11.7	31.3	18.7	34.7	16.2	56.2	13.1	27.0	9.3	57.5	13.8	41.4
		Robust Plugs	27.8	55.2	25.1	43.1	21.9	38.0	25.9	33.2	17.5	37.6	23.7	41.4
10	F	Seeds	18.7	13.2	16.3	41.9	17.9	14.1	14.7	34.6	–	–	16.9	26.0
		Seedlings	26.2	15.7	20.8	22.5	24.0	25.0	17.8	31.3	20.1	23.3	21.8	23.5
		Rooted Cuttings, R	25.3	22.2	26.6	28.7	29.4	28.3	24.8	37.6	20.7	30.0	25.5	29.4
		Rooted Cuttings, D.	15.0	36.1	21.1	25.5	22.1	22.7	17.5	22.0	17.3	16.6	[illegible]	24.6
		Robust Plugs	20.3	32.9	25.6	4.4	30.2	17.4	22.0	24.1	24.9	30.0	24.6	21.8
	U	Seeds	18.2	32.2	19.4	43.2	15.2	36.9	16.4	34.9	–	–	17.4	36.8
		Seedlings	18.8	24.4	22.3	28.9	18.5	30.0	17.8	29.7	20.8	31.2	19.6	28.8
		Rooted Cuttings, R.	30.0	0	24.0	42.0	24.5	29.7	22.3	25.7	30.1	10.0	26.2	21.5
		Rooted Cuttings, D.	16.0	28.8	19.4	31.2	22.5	25.0	14.2	27.0	17.9	14.1	18.0	25.2
		Robust Plugs	29.3	21.7	32.3	23.8	27.3	17.9	29.8	14.0	25.5	26.9	28.8	21.9

Survival and Growth of Test Plantings

Table 4. Showing mean percent survival, during the May-October period, of three growth forms of Salicornia pacifica Standl. planted in fertilized (F) and unfertilized (U) plots in mid-May, 1974, at the Alameda Creek Experimental Area. The means of each of the three plot means are given.

Months	Treated	Planting Stock	Plots 1 $\bar{x}$	Plots 1 C.V.	Plots 2 $\bar{x}$	Plots 2 C.V.	Plots 3 $\bar{x}$	Plots 3 C.V.	Mean of Plot Means	C.V. %
5	F	Seedlings								
		Rooted Cuttings								
		Unrooted Cuttings								
	U	Seedlings	100						100	
		Rooted Cuttings	100						100	
		Unrooted Cuttings	—						—	
8	F	Seedlings	92		80		68		80	
		Rooted Cuttings	88		100		88		92	
		Unrooted Cuttings	100		100		100		100	
	U	Seedlings	88		76		44		69.3	
		Rooted Cuttings	100		32		40		57.3	
		Unrooted Cuttings	100		100		100		100	
10	F	Seedlings	76		76		68		73.3	
		Rooted Cuttings	0		92		92		61.3	
		Unrooted Cuttings	0		37.5		0		12.5	
	U	Seedlings	88		72		32		64	
		Rooted Cuttings	76		32		36		48	
		Unrooted Cuttings	100		0		0		33.3	

Survival and Growth of Test Plantings

Table 5. Showing mean numbers of stems per plot of the three growth forms of Salicornia pacifica Standl. plantes in fertilized (F) and unfertilized (U) plots in mid-May, 1974, at the Alameda Creek Experimental Area. The means of each of the three plot means and the coefficients of variation (%) are given.

Months	Treated	Planting Stock	Plots 1 $\bar{x}$	Plots 1 C.V.	Plots 2 $\bar{x}$	Plots 2 C.V.	Plots 3 $\bar{x}$	Plots 3 C.V.	Mean of Plot Means	C.V. %
5	F	Seedlings								
		Rooted Cuttings								
		Unrooted Cuttings								
	U	Seedlings	1.4	50.0					1.4	50.0
		Rooted Cuttings	6.2	49.7					6.2	49.7
		Unrooted Cuttings	—	—					—	
8	F	Seedlings	6.7	94.3	4.7	79.0	10.1	71.6	7.2	81.6
		Rooted Cuttings	5.9	64.2	7.8	89.4	13.8	50.4	9.2	68.0
		Unrooted Cuttings	3.2	71.3	7.0	67.4	0	0	3.4	46.2
	U	Seedlings	5.5	55.3	3.7	96.0	3.9	55.5	4.4	68.9
		Rooted Cuttings	8.7	64.9	7.0	45.1	6.9	49.0	7.5	53.0
		Unrooted Cuttings	10	0	2	0	0	0	4	0
10	F	Seedlings	19.8	73.5	21.2	105.4	42.2	82.8	27.7	87.2
		Rooted Cuttings	0	0	17.2	95.0	49.2	63.0	22.1	52.7
		Unrooted Cuttings	0	0	16.3	64.9	0	0	5.4	26.6
	U	Seedlings	20.7	90.0	15.1	84.7	16.4	80.5	17.3	25.1
		Rooted Cuttings	18.3	51.6	26.7	93.8	24.2	55.0	23.1	66.8
		Unrooted Cuttings	30.0	0	0	0	0	0	10	0

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Survival and Growth of Test Plantings

Table 6. Showing mean growth in height (cm) per plot of three growth forms of Salicornia pacifica Standl. planted in fertilized (F) and unfertilized (U) plots in mid-May, 1974, at the Alameda Creek Experimental Area. The means of each of the three plot means and the coefficients of variation (%) are given.

Months	Treated	Planting Stock	Plots 1 $\bar{x}$	Plots 1 C.V.	Plots 2 $\bar{x}$	Plots 2 C.V.	Plots 3 $\bar{x}$	Plots 3 C.V.	Mean of Plot Means	C.V. %
5	F	Seedlings								
		Rooted Cuttings								
		Unrooted Cuttings								
	U	Seedlings	11.1	31.9					11.1	31.9
		Rooted Cuttings	20.3	333					20.3	33.3
		Unrooted Cuttings	—	—					—	—
8	F	Seedlings	17.8	35.1	17.5	52.4	17.0	43.8	17.4	43.8
		Rooted Cuttings	18.7	39.6	19.2	32.7	23.0	36.0	20.3	36.1
		Unrooted Cuttings	11.4	49.2	15.1	51.5	0	0	8.9	33.6
	U	Seedlings	15.5	32.0	15.4	36.7	13.1	36.2	14.7	35.0
		Rooted Cuttings	20.9	50.0	17.8	44.5	16.0	44.2	18.2	46.2
		Unrooted Cuttings	27.5	0	14.0	0	0	0	13.8	0
10	F	Seedlings	25.9	35.0	32.7	36.4	37.3	30.8	32.0	34.1
		Rooted Cuttings	0	0	22.7	36.2	34.0	35.7	18.9	24.0
		Unrooted Cuttings	0	0	34.0	27.6	0	0	11.3	9.2
	U	Seedlings	26.8	32.6	23.2	39.5	26.5	54.9	25.5	42.3
		Rooted Cuttings	28.1	32.3	28.3	30.3	25.7	21.5	27.4	28.0
		Unrooted Cuttings	57.5	0	0	0	0	0	19.2	0

Survival and Growth of Test Plantings

Table 7. Showing mean growth in dry weight of shoots (one randomly selected plant from each plot replicate) of five growth forms of Spartina foliosa Trin. planted in fertilized (F) and unfertilized (U) plots in mid-May, 1974, at the Alameda Creek Experimental area. The means of each of the five plot means, and the corresponding coefficients of variation are given.

Months	Treatment	Planting Stock	Plots 1 $\bar{x}$	1 C.V.	2 $\bar{x}$	2 C.V.	3 $\bar{x}$	3 C.V.	4 $\bar{x}$	4 C.V.	5 $\bar{x}$	5 C.V.	Mean of Plot Means	C.V. %
5	F	Seeds												
		Seedlings												
		Rooted Cuttings, R.												
		Rooted Cuttings, D.												
		Robust Plugs												
	U	Seeds												
		Seedlings	0.021										0.021	
		Rooted Cuttings, R.	0.93										0.93	
		Rooted Cuttings, D.	0.28										0.28	
		Robust Plugs	6.51										6.51	
8	F	Seeds												
		Seedlings												
		Rooted Cuttings, R												
		Rooted Cuttings, D												
		Robust Plugs												
	U	Seeds												
		Seedlings												
		Rooted Cuttings, R												
		Rooted Cuttings, D												
		Robust Plugs												
10	F	Seeds	0.29		0.19		0.21		0.63		—		0.33	
		Seedlings	2.1		0.90		0.42		0.82		0.24		0.90	
		Rooted Cuttings, R	0.76		1.77		0.63		1.50		0.63		1.06	
		Rooted Cuttings, D.	1.02		1.58		2.25		0.39		0.21		1.09	
		Robust Plugs	3.74		2.87		5.39		2.48		0.69		3.03	
	U	Seeds	0.42		0.26		0.35		0.16		—		0.30	
		Seedlings	0.59		0.56		0.36		0.36		0.64		0.50	
		Rooted Cuttings, R.	1.44		2.20		1.29		1.13		2.93		1.80	
		Rooted Cuttings, D.	2.35		0.77		0.32		0.20		0.71		0.87	
		Robust Plugs	3.42		4.45		1.51		1.52		1.23		2.43	

Survival and Growth of Test Plantings

Table 8. Showing mean growth in dry weight of roots (one randomly selected plant from each plot replicate) of five growth forms of Spartina foliosa Trin. planted in fertilized (F) and unfertilized (U) plots in mid-May, 1974, at the Alameda Creek Experimental area. The means of each of the five plot means, and the corresponding coefficients of variation is given.

Months	Treatment	Planting Stock	Plot 1 $\bar{x}$	Plot 1 C.V.	Plot 2 $\bar{x}$	Plot 2 C.V.	Plot 3 $\bar{x}$	Plot 3 C.V.	Plot 4 $\bar{x}$	Plot 4 C.V.	Plot 5 $\bar{x}$	Plot 5 C.V.	Mean of Plot Means	C.V. %
5	F	Seeds												
		Seedlings												
		Rooted Cuttings, R.												
		Rooted Cuttings, D.												
		Robust Plugs												
	U	Seeds												
		Seedlings	0.017										0.017	
		Rooted Cuttings, R.	2.44										2.44	
		Rooted Cuttings, D.	0.402										0.402	
		Robust Plugs	8.78										8.78	
8	F	Seeds												
		Seedlings												
		Rooted Cuttings, R												
		Rooted Cuttings, D												
		Robust Plugs												
	U	Seeds												
		Seedlings												
		Rooted Cuttings, R												
		Rooted Cuttings, D												
		Robust Plugs												
10	F	Seeds	0.25		0.09		0.36		1.02		—		0.43	
		Seedlings	3.73		1.05		0.44		1.18		0.18		1.32	
		Rooted Cuttings, R	2.31		2.42		1.71		7.52		7.26		4.34	
		Rooted Cuttings, D.	1.81		3.45		3.21		0.84		2.34		2.34	
		Robust Plugs	42.6		14.8		20.3		13.2		9.1		20.0	
	U	Seeds	0.44		0.28		0.58		0.18		—		0.37	
		Seedlings	1.17		0.87		0.19		1.08		1.16		0.89	
		Rooted Cuttings, R	4.75		12.9		3.4		10.0		6.3		7.46	
		Rooted Cuttings, D	5.06		1.70		0.62		0.65		2.78		2.16	
		Robust Plugs	34.9		28.9		1.2		3.5		6.5		15.01	

Survival and Growth of Test Plantings

Table 9. Showing mean growth in dry weight (g.) of shoots (one randomly selected plant from each plot replicate) of three growth forms of Salicornia pacifica Standl. planted in fertilized (F) and unfertilized (U) plots in mid-May, 1974, at the Alameda Creek Experimental Area. The means of each of the three plot means are given.

Months	Treated	Planting Stock	Plot 1 $\bar{x}$	Plot 1 C.V.	Plot 2 $\bar{x}$	Plot 2 C.V.	Plot 3 $\bar{x}$	Plot 3 C.V.	Mean of Plot Means	C.V. %
5	F	Seedlings								
		Rooted Cuttings								
		Unrooted Cuttings								
	U	Seedlings	0.257						0.257	
		Rooted Cuttings	0.807						0.807	
		Unrooted Cuttings	—						—	
8	F	Seedlings								
		Rooted Cuttings								
		Unrooted Cuttings								
	U	Seedlings								
		Rooted Cuttings								
		Unrooted Cuttings								
10	F	Seedlings	14.7		45.7		30.2		30.2	
		Rooted Cuttings	34.1		48.2		—		27.4	
		Unrooted Cuttings	—		13.0		—		4.3	
	U	Seedlings	12.0		8.8		12.3		11.0	
		Rooted Cuttings	9.5		5.7		13.8		9.7	
		Unrooted Cuttings	33.3		—		—		11.1	

Survival and Growth of Test Plantings

Table **10**. Showing mean growth in dry weight (g.) of roots (one randomly selected plant from each plot replicate) of three growth forms of Salicornia pacifica Standl. planted in fertilized (F) and unfertilized (U) plots in mid-May, 1974, at the Alameda Creek Experimental Area. The means of each of the three plot means are given.

Months	Treated	Planting Stock	Plots 1 $\bar{x}$	Plots 1 C.V.	Plots 2 $\bar{x}$	Plots 2 C.V.	Plots 3 $\bar{x}$	Plots 3 C.V.	Means of Plot Means	C.V. %
5	F	Seedlings								
		Rooted Cuttings								
		Unrooted Cuttings								
	U	Seedlings	0.10						0.10	
		Rooted Cuttings	0.302						0.302	
		Unrooted Cuttings	—						—	
8	F	Seedlings								
		Rooted Cuttings								
		Unrooted Cuttings								
	U	Seedlings								
		Rooted Cuttings								
		Unrooted Cuttings								
10	F	Seedlings	1.81		3.49		2.65		2.65	
		Rooted Cuttings	6.78		7.51		—		4.76	
		Unrooted Cuttings	—		3.23		—		1.08	
	U	Seedlings	2.44		3.54		1.58		2.52	
		Rooted Cuttings	2.60		1.86		1.13		1.86	
		Unrooted Cuttings	5.15		—		—		1.72	

APPENDIX H

DATA FOR INDIVIDUAL TEST PLOTS

TEST CONDITIONS, 1 to 16.

Odd Numbers - Fertilized Conditions.

Even Numbers = Unfertilized Conditions.

Test Conditions

	Spartina
1 and 2	Seeds
3 and 4	Robust Rooted Cuttings
5 and 6	Seedlings
7 and 8	Robust Plugs
9 and 10	Dwarf Rooted Cuttings
	Salicornia
11 and 12	Shoots--Unrooted cuttings
13 and 14	Rooted Cuttings
15 and 16	Seedlings

SPARTINA SEEDS

TEST CONDITIONS 1 & 2

			1	PLOT REPLICATES				
			1	2	3	4	5	MEAN
MAY	FERTILIZER	TOTAL NUMBER PLANTS						—
		MEAN HEIGHT						—
		MEAN NUMBER STEMS						—
		PERCENT SURVIVAL						—
		MEAN WEIGHT SHOOTS						—
		MEAN WEIGHT ROOTS						—
	NO FERTILIZER	TOTAL NUMBER PLANTS						—
		MEAN HEIGHT						—
		MEAN NUMBER STEMS						—
		PERCENT SURVIVAL						—
		MEAN WEIGHT SHOOTS						—
		MEAN WEIGHT ROOTS						—
								—
AUGUST	FERTILIZER	TOTAL NUMBER PLANTS	2	26	38	22	-	22
		MEAN HEIGHT	11.6	8.47	9.91	7.92	-	9.48
		MEAN NUMBER STEMS	1.5	1.0	2.3	1.0	-	1.45
		PERCENT SURVIVAL	100	100	100	100	-	100
		VOLUNTEERS S.PACIFICA	5	4	4	1	-	3.5
		VOLUNTEERS S. RUBRA	0	1	2	3	-	1.5
		TOTAL VOLUNTEERS	5	5	6	4	-	5
		MEAN HEIGHT VOLUNTEERS	12.18	14.66	21.9	13.43	-	15.54
		MEAN STEMS VOLUNTEERS	8.2	6.0	7.67	6.25	-	7.03
	NO FERTILIZER	TOTAL NUMBER PLANTS	35	27	107	134	-	75.75
		MEAN HEIGHT	7.85	7.07	12.22	9.68	-	9.21
		MEAN NUMBER STEMS	1.0	1.0	1.6	1.0	-	1.15
		PERCENT SURVIVAL	100	100	100	100	-	100
		VOLUNTEERS S.PACIFICA	3	2	0	0	-	1.25
		VOLUNTEERS S. RUBRA	0	2	0	0	-	0.5
		TOTAL VOLUNTEERS	3	4	0	0	-	1.75
		MEAN HEIGHT VOLUNTEERS	20.6	20.1	0	0	-	10.18
		MEAN STEMS VOLUNTEERS	9.0	6.5	0	0	-	3.88
OCTOBER	FERTILIZER	TOTAL NUMBER PLANTS	5	20	9	11	-	11.25
		MEAN HEIGHT	18.74	16.28	17.92	14.66	-	16.9
		MEAN NUMBER STEMS	2.6	2.35	5.0	3.18	-	3.28
		PERCENT SURVIVAL	250	77	24	50	-	100.25
		MEAN WEIGHT SHOOTS	0.29	0.19	0.21	0.63	-	0.33
		MEAN WEIGHT ROOTS	0.25	0.09	0.36	1.02	-	0.43
		TOTAL VOLUNTEERS	5	3	0	2	-	2.5
		MEAN HEIGHT VOLUNTEERS	24.66	21.67	0	20.85	-	16.8
		MEAN STEMS VOLUNTEERS	16.4	27.33	0	7.5	-	12.81
	NO FERTILIZER	TOTAL NUMBER PLANTS	31	29	83	70	-	53.25
		MEAN HEIGHT	18.17	19.94	15.17	16.38	-	17.42
		MEAN NUMBER STEMS	1.87	1.97	1.45	1.63	-	1.73
		PERCENT SURVIVAL	89	107	78	52	-	81.5
		MEAN WEIGHT SHOOTS	0.42	0.26	0.35	0.16	-	0.3
		MEAN WEIGHT ROOTS	0.44	0.28	0.58	0.18	-	0.37
		TOTAL VOLUNTEERS	3	8	1	2	-	3.5
		MEAN HEIGHT VOLUNTEERS	24.83	23.65	20.0	25.1	-	24.65
		MEAN STEMS VOLUNTEERS	19.0	10.38	7.0	8.5	-	11.22

BEST AVAILABLE COPY

SPARTINA ROBUST ROOTED CUTTINGS

TEST CONDITIONS 3 & 4

			PLOT REPLICATES					
			1	2	3	4	5	MEAN
MAY	FERTILIZER	TOTAL NUMBER PLANTS	10					10
		MEAN HEIGHT	37.9					37.9
		MEAN NUMBER STEMS	1.3					1.3
		PERCENT SURVIVAL	100					100
		MEAN WEIGHT SHOOTS	0.93					0.93
		MEAN WEIGHT ROOTS	2.44					2.44
	NO FERTILIZER	TOTAL NUMBER PLANTS						
		MEAN HEIGHT						
		MEAN NUMBER STEMS						
		PERCENT SURVIVAL						
		MEAN WEIGHT SHOOTS						
		MEAN WEIGHT ROOTS						
AUGUST	FERTILIZER	TOTAL NUMBER PLANTS	11	15	10	5	7	9.6
		MEAN HEIGHT	19.7	17.35	17.36	17.84	10.63	16.57
		MEAN NUMBER STEMS	1.64	2.8	2.6	1.4	1.0	1.89
		PERCENT SURVIVAL	44	60	40	20	28	38.4
		VOLUNTEERS S.PACIFICA	2	12	27	1	0	8.4
		VOLUNTEERS S. RUBRA	0	2	0	2	0	0.8
		TOTAL VOLUNTEERS	2	14	27	3	0	9.2
		MEAN NEIGHT VOLUNTEERS	12.2	15.37	6.83	15.17	0	9.91
		MEAN STEMS VOLUNTEERS	6.5	5.36	1.63	9.67	0	4.63
	NO FERTILIZER	TOTAL NUMBER PLANTS	2	6	9	9	6	6.4
		MEAN HEIGHT	15.35	16.3	16.42	10.52	17.4	15.2
		MEAN NUMBER STEMS	1.0	1.83	2.22	1.67	1.83	1.71
		PERCENT SURVIVAL	8	24	36	36	24	25.6
		VOLUNTEERS S.PACIFICA	2	7	8	0	13	6
		VOLUNTEERS S. RUBRA	0	2	2	12	0	3.2
		TOTAL VOLUNTEERS	2	9	10	12	13	9.2
		MEAN HEIGHT VOLUNTEERS	16.0	10.42	9.72	13.45	11.12	12.14
		MEAN STEMS VOLUNTEERS	7.5	3.33	2.6	5.5	3.08	4.4
OCTOBER	FERTILIZER	TOTAL NUMBER PLANTS	11	20	6	4	3	8.8
		MEAN HEIGHT	25.26	26.64	29.87	24.85	20.67	25.46
		MEAN NUMBER STEMS	2.64	5.9	4.5	3.25	2.0	3.66
		PERCENT SURVIVAL	44	80	24	16	12	35.2
		MEAN WEIGHT SHOOTS	.76	1.77	.63	1.50	.62	1.06
		MEAN WEIGHT ROOTS	2.31	2.92	1.71	7.52	7.26	4.34
		TOTAL VOLUNTEERS	0	10	14	2	3	5.8
		MEAN HEIGHT VOLUNTEERS	0	27.05	24.17	26.2	16.57	18.8
		MEAN STEMS VOLUNTEERS	0	12.5	9.9	19.5	10.0	10.38
	NO FERTILIZER	TOTAL NUMBER PLANTS	1	4	11	7	3	5.2
		MEAN HEIGHT	30.0	24.0	24.5	22.33	30.13	26.19
		MEAN NUMBER STEMS	2.0	3.75	3.27	3.86	4.0	3.38
		PERCENT SURVIVAL	4	16	44	28	12	20.8
		MEAN WEIGHT SHOOTS	1.44	2.2	1.29	1.13	2.93	1.8
		MEAN WEIGHT ROOTS	4.75	12.86	3.36	10.04	6.29	7.46
		TOTAL VOLUNTEERS	2	4	16	12	6	8
		MEAN HEIGHT VOLUNTEERS	22.4	23.98	21.84	21.64	27.67	23.51
		MEAN STEMS VOLUNTEERS	14.0	11.5	9.25	11.17	12.0	11.58

SPARTINA SEEDLINGS

TEST CONDITIONS 5 & 6

			PLOT REPLICATES					
			1	2	3	4	5	MEAN
MAY	FERTILIZER	TOTAL NUMBER PLANTS	10					10
		MEAN HEIGHT	8.41					8.41
		MEAN NUMBER STEMS	1.0					1.0
		PERCENT SURVIVAL	100					100
		MEAN WEIGHT SHOOTS	0.02					0.02
		MEAN WEIGHT ROOTS	0.02					0.02
	NO FERTILIZER	TOTAL NUMBER PLANTS						
		MEAN HEIGHT						
		MEAN NUMBER STEMS						
		PERCENT SURVIVAL						
		MEAN WEIGHT SHOOTS						
		MEAN WEIGHT ROOTS						
AUGUST	FERTILIZER	TOTAL NUMBER PLANTS	11	25	17	11	12	15.2
		MEAN HEIGHT	13.79	16.02	17.67	13.75	11.19	14.48
		MEAN NUMBER STEMS	2.55	3.6	4.12	2.91	2.0	3.04
		PERCENT SURVIVAL	44	100	68	44	48	60.8
		VOLUNTEERS S. PACIFICA	0	0	0	0	1	0.2
		VOLUNTEERS S. RUBRA	0	1	0	11	0	2.4
		TOTAL VOLUNTEERS	0	1	0	11	1	2.6
		MEAN HEIGHT VOLUNTEERS	0	16.2	0	10.57	6.0	6.55
		MEAN STEMS VOLUNTEERS	0	9.0	0	3.55	1.0	2.71
	NO FERTILIZER	TOTAL NUMBER PLANTS	16	17	14	16	10	14.6
		MEAN HEIGHT	15.05	15.57	12.44	13.54	12.83	13.89
		MEAN NUMBER STEMS	2.81	3.47	2.93	2.19	2.1	2.7
		PERCENT SURVIVAL	64	68	56	64	40	58.4
		VOLUNTEERS S. PACIFICA	8	29	1	1	11	10.0
		VOLUNTEERS S. RUBRA	0	1	10	1	0	2.4
		TOTAL VOLUNTEERS	8	30	11	1	11	12.2
		MEAN HEIGHT VOLUNTEERS	8.25	10.29	15.97	12.7	10.96	11.63
		MEAN STEMS VOLUNTEERS	3.12	4.13	4.36	3.5	3.73	3.77
OCTOBER	FERTILIZER	TOTAL NUMBER PLANTS	9	21	16	11	9	13.2
		MEAN HEIGHT	26.19	20.82	24.0	17.85	20.09	21.79
		MEAN NUMBER STEMS	8.22	7.0	7.25	10.0	7.56	8.01
		PERCENT SURVIVAL	36	84	64	44	36	52.8
		MEAN WEIGHT SHOOTS	2.1	.9	.42	.82	.24	0.9
		MEAN WEIGHT ROOTS	3.73	1.05	.44	1.18	.18	1.32
		TOTAL VOLUNTEERS	2	3	5	9	1	4
		MEAN HEIGHT VOLUNTEERS	21.25	19.7	22.8	22.51	25.0	22.25
		MEAN STEMS VOLUNTEERS	10.0	8.67	8.2	9.11	8.0	8.8
	NO FERTILIZER	TOTAL NUMBER PLANTS	15	15	17	15	7	13.8
		MEAN HEIGHT	18.77	22.35	18.49	17.84	20.8	19.65
		MEAN NUMBER STEMS	4.6	6.87	6.0	6.6	6.57	6.13
		PERCENT SURVIVAL	60	60	68	60	28	55.2
		MEAN WEIGHT SHOOTS	.59	0.56	0.36	0.36	0.64	.5
		MEAN WEIGHT ROOTS	1.17	0.87	0.19	1.08	1.16	.89
		TOTAL VOLUNTEERS	10	37	12	2	13	14.8
		MEAN HEIGHT VOLUNTEERS	21.72	23.89	23.28	15.75	27.25	22.38
		MEAN STEMS VOLUNTEERS	12.2	7.03	12.08	9.0	10.15	10.09

ROBUST SPARTINA PLUGS

TEST CONDITION 7 & 8

Month	Treatment	Parameter	Plot Replicates 1	2	3	4	5	MEAN
MAY	FERTILIZER	TOTAL NUMBER PLANTS	10					10
		MEAN HEIGHT	55.3					55.3
		MEAN NUMBER STEMS	5.2					5.2
		PERCENT SURVIVAL	100					100
		MEAN WEIGHT SHOOTS	6.51					6.51
		MEAN WEIGHT ROOTS	8.78					8.78
	NO FERTILIZER	TOTAL NUMBER PLANTS						
		MEAN HEIGHT						
		MEAN NUMBER STEMS						
		PERCENT SURVIVAL						
		MEAN WEIGHT SHOOTS						
		MEAN WEIGHT ROOTS						
AUGUST	FERTILIZER	TOTAL NUMBER PLANTS	23	25	24	23	22	23.4
		MEAN HEIGHT	12.93	21.86	27.79	21.3	21.27	21.03
		MEAN NUMBER STEMS	4.7	4.24	4.88	3.87	4.0	4.34
		PERCENT SURVIVAL	92	100	96	92	88	93.6
		VOLUNTEERS S. PACIFICA	0	0	0	0	26	5.2
		VOLUNTEERS S. RUBRA	0	1	0	2	0	0.6
		TOTAL VOLUNTEERS	0	1	0	2	26	5.8
		MEAN HEIGHT VOLUNTEERS	0	12.2	0	16.25	10.75	7.84
		MEAN STEMS VOLUNTEERS	0	5.0	0	6.0	3.73	2.95
	NO FERTILIZER	TOTAL NUMBER PLANTS	15	22	23	24	19	20.6
		MEAN HEIGHT	27.83	25.1	21.94	25.88	17.54	23.66
		MEAN NUMBER STEMS	3.93	4.91	4.74	4.13	2.95	4.13
		PERCENT SURVIVAL	60	88	92	96	76	82.4
		VOLUNTEERS S. PACIFICA	3	3	10	4	0	4.0
		VOLUNTEERS S. RUBRA	0	1	2	0	0	0.6
		TOTAL VOLUNTEERS	3	4	12	4	0	4.6
		MEAN HEIGHT VOLUNTEERS	12.3	11.93	14.1	8.8	0	9.43
		MEAN STEMS VOLUNTEERS	3.0	4.25	6.5	5.75	0	3.9
OCTOBER	FERTILIZER	TOTAL NUMBER PLANTS	24	21	18	22	19	20.8
		MEAN HEIGHT	20.3	25.56	30.17	22.04	24.92	24.6
		MEAN NUMBER STEMS	6.04	6.48	8.28	6.27	7.42	6.9
		PERCENT SURVIVAL	96	84	72	88	76	83.2
		MEAN WEIGHT SHOOTS	3.74	2.87	5.39	2.48	0.69	3.03
		MEAN WEIGHT ROOTS	42.59	14.85	20.32	13.21	9.09	20.01
		TOTAL VOLUNTEERS	1	1	0	0	22	4.8
		MEAN HEIGHT VOLUNTEERS	30.0	19.0	0	0	26.99	15.2
		MEAN STEMS VOLUNTEERS	9.0	12.0	0	0	7.82	5.76
	NO FERTILIZER	TOTAL NUMBER PLANTS	13	23	23	21	16	19.2
		MEAN HEIGHT	29.33	32.29	27.31	29.83	25.47	28.85
		MEAN NUMBER STEMS	5.69	6.91	6.3	6.24	6.19	6.27
		PERCENT SURVIVAL	52	92	92	84	64	76.8
		MEAN WEIGHT SHOOTS	3.42	4.45	1.51	1.52	1.23	2.43
		MEAN WEIGHT ROOTS	34.9	28.34	1.16	3.49	6.55	15.01
		TOTAL VOLUNTEERS	2	8	24	4	3	8.2
		MEAN HEIGHT VOLUNTEERS	26.0	20.34	22.85	23.38	19.57	22.43
		MEAN STEMS VOLUNTEERS	5.5	9.25	9.25	9.75	11.67	9.08

SPARTINA DWARF ROOTED CUTTINGS

TEST CONDITIONS 9 & 10

			PLOT REPLICATES					
			1	2	3	4	5	MEAN
MAY	FERTILIZER	TOTAL NUMBER PLANTS	10					10
		MEAN HEIGHT	20.35					20.35
		MEAN NUMBER STEMS	2.1					2.1
		PERCENT SURVIVAL	100					100
		MEAN WEIGHT SHOOTS	0.28					0.28
		MEAN WEIGHT ROOTS	0.4					0.4
	NO FERTILIZER	TOTAL NUMBER PLANTS						
		MEAN HEIGHT						
		MEAN NUMBER STEMS						
		PERCENT SURVIVAL						
		MEAN WEIGHT SHOOTS						
		MEAN WEIGHT ROOTS						
AUGUST	FERTILIZER	TOTAL NUMBER PLANTS	22	21	24	18	17	20.4
		MEAN HEIGHT	15.87	16.41	17.03	14.68	13.41	15.48
		MEAN NUMBER STEMS	2.46	4.48	3.75	2.67	2.29	3.13
		PERCENT SURVIVAL	88	84	96	72	68	81.6
		VOLUNTEERS S. PACIFICA	5	11	14	8	0	7.6
		VOLUNTEERS S. RUBRA	0	2	1	0	6	1.8
		TOTAL VOLUNTEERS	5	13	15	8	6	9.4
		MEAN HEIGHT VOLUNTEERS	10.44	12.49	10.28	20.96	13.68	13.57
		MEAN STEMS VOLUNTEERS	4.0	6.0	3.73	5.5	6.5	5.15
	NO FERTILIZER	TOTAL NUMBER PLANTS	18	15	19	18	10	16
		MEAN HEIGHT	11.74	18.67	16.22	13.09	9.35	13.81
		MEAN NUMBER STEMS	2.56	3.07	2.74	1.78	1.7	2.37
		PERCENT SURVIVAL	72	60	76	72	40	64
		VOLUNTEERS S. PACIFICA	10	18	21	0	0	9.8
		VOLUNTEERS S. RUBRA	1	3	3	2	0	1.8
		TOTAL VOLUNTEERS	11	21	24	2	0	11.6
		MEAN HEIGHT VOLUNTEERS	14.66	8.56	11.03	10.35	0	8.92
		MEAN STEMS VOLUNTEERS	6.27	2.52	3.88	3.5	0	3.23
OCTOBER	FERTILIZER	TOTAL NUMBER PLANTS	15	19	23	18	16	18.2
		MEAN HEIGHT	15.05	21.09	22.09	17.53	17.34	18.62
		MEAN NUMBER STEMS	4.33	8.42	6.57	4.61	5.44	5.87
		PERCENT SURVIVAL	60	76	92	72	64	72.8
		MEAN WEIGHT SHOOTS	1.02	1.58	2.25	.39	.21	1.09
		MEAN WEIGHT ROOTS	1.81	3.45	3.21	.84	2.39	2.34
		TOTAL VOLUNTEERS	5	16	15	11	10	11.4
		MEAN HEIGHT VOLUNTEERS	22.4	25.13	20.75	26.1	23.71	23.62
		MEAN STEMS VOLUNTEERS	9.4	10.94	7.27	13.82	12.0	10.69
	NO FERTILIZER	TOTAL NUMBER PLANTS	18	17	23	16	9	16.6
		MEAN HEIGHT	16.03	19.44	22.59	14.19	17.92	18.02
		MEAN NUMBER STEMS	4.61	5.53	6.48	4.69	5.0	5.26
		PERCENT SURVIVAL	72	68	92	64	36	66.4
		MEAN WEIGHT SHOOTS	2.35	0.77	0.32	0.2	0.71	0.87
		MEAN WEIGHT ROOTS	5.06	1.7	0.62	.65	2.78	2.16
		TOTAL VOLUNTEERS	9	14	33	0	0	11.2
		MEAN HEIGHT VOLUNTEERS	22.67	20.99	23.58	0	0	13.45
		MEAN STEMS VOLUNTEERS	11.33	6.86	12.97	0	0	6.23

SALICORNIA UNROOTED CUTTINGS

TEST CONDITIONS 11 & 12

			PLOT REPLICATES					
			1	2	3	4	5	MEAN
MAY	FERTILIZER	TOTAL NUMBER PLANTS	—					—
		MEAN HEIGHT	—					—
		MEAN NUMBER STEMS	—					—
		PERCENT SURVIVAL	—					—
		MEAN WEIGHT SHOOTS	—					—
		MEAN WEIGHT ROOTS	—					—
	NO FERTILIZER	TOTAL NUMBER PLANTS						—
		MEAN HEIGHT						—
		MEAN NUMBER STEMS						—
		PERCENT SURVIVAL						—
		MEAN WEIGHT SHOOTS						—
		MEAN WEIGHT ROOTS						—
								—
AUGUST	FERTILIZER	TOTAL NUMBER PLANTS	55	8	0			21
		MEAN HEIGHT	11.44	15.08	0			8.84
		MEAN NUMBER STEMS	3.2	7.0	0			3.4
		PERCENT SURVIVAL	100	100	100			100
		VOLUNTEERS S.PACIFICA	—	—	—			—
		VOLUNTEERS S. RUBRA	0	0	0			0
		TOTAL VOLUNTEERS	0	0	0			0
		MEAN HEIGHT VOLUNTEERS	0	0	0			0
		MEAN STEMS VOLUNTEERS	0	0	0			0
	NO FERTILIZER	TOTAL NUMBER PLANTS	1	1	0			.67
		MEAN HEIGHT	27.5	14.0	0			13.83
		MEAN NUMBER STEMS	10	2.0	0			4.0
		PERCENT SURVIVAL	100	100	0			66.67
		VOLUNTEERS S.PACIFICA	—	—	—			—
		VOLUNTEERS S. RUBRA	0	0	0			0
		TOTAL VOLUNTEERS	0	0	0			0
		MEAN HEIGHT VOLUNTEERS	0	0	0			0
		MEAN STEMS VOLUNTEERS	0	0	0			0
OCTOBER	FERTILIZER	TOTAL NUMBER PLANTS	0	3	0			1.0
		MEAN HEIGHT	0	34.0	0			11.33
		MEAN NUMBER STEMS	0	16.33	0			5.44
		PERCENT SURVIVAL	0	37.5	0			12.5
		MEAN WEIGHT SHOOTS	—	13.03	—			4.34
		MEAN WEIGHT ROOTS	—	3.23	—			1.08
		TOTAL VOLUNTEERS	0	0	0			0
		MEAN HEIGHT VOLUNTEERS	0	0	0			0
		MEAN STEMS VOLUNTEERS	0	0	0			0
	NO FERTILIZER	TOTAL NUMBER PLANTS	1	0	0			.33
		MEAN HEIGHT	57.5	0	0			19.17
		MEAN NUMBER STEMS	30.0	0	0			10.0
		PERCENT SURVIVAL	100	0	0			33.3
		MEAN WEIGHT SHOOTS	33.3	0	0			11.1
		MEAN WEIGHT ROOTS	5.15	0	0			1.72
		TOTAL VOLUNTEERS	0	0	0			0
		MEAN HEIGHT VOLUNTEERS	0	0	0			0
		MEAN STEMS VOLUNTEERS	0	0	0			0

SALICORNIA ROOTED CUTTINGS

TEST CONDITIONS 13 & 14

			PLOT REPLICATES					
			1	2	3	4	5	MEAN
MAY	FERTILIZER	TOTAL NUMBER PLANTS	10					10
		MEAN HEIGHT	20.27					20.27
		MEAN NUMBER STEMS	6.2					6.2
		PERCENT SURVIVAL	100					100
		MEAN WEIGHT SHOOTS	0.81					0.81
		MEAN WEIGHT ROOTS	0.302					0.302
	NO FERTILIZER	TOTAL NUMBER PLANTS						
		MEAN HEIGHT						
		MEAN NUMBER STEMS						
		PERCENT SURVIVAL						
		MEAN WEIGHT SHOOTS						
		MEAN WEIGHT ROOTS						
AUGUST	FERTILIZER	TOTAL NUMBER PLANTS	22	25	22			23
		MEAN HEIGHT	18.69	19.24	23.02			20.32
		MEAN NUMBER STEMS	5.86	7.84	13.82			9.17
		PERCENT SURVIVAL	88	100	88			92
		VOLUNTEERS S.PACIFICA	18	0	2			6.67
		VOLUNTEERS S. RUBRA	0	0	0			0
		TOTAL VOLUNTEERS	18	0	2			6.67
		MEAN HEIGHT VOLUNTEERS	18.43	0	23.15			13.86
		MEAN STEMS VOLUNTEERS	7.06	0	9.0			5.35
	NO FERTILIZER	TOTAL NUMBER PLANTS	25	8	10			14.33
		MEAN HEIGHT	20.88	17.83	16.03			18.25
		MEAN NUMBER STEMS	8.68	7.0	6.9			7.53
		PERCENT SURVIVAL	100	32	40			57.33
		VOLUNTEERS S.PACIFICA	0	0	0			0
		VOLUNTEERS S. RUBRA	0	0	0			0
		TOTAL VOLUNTEERS	0	0	0			0
		MEAN HEIGHT VOLUNTEERS	0	0	0			0
		MEAN STEMS VOLUNTEERS	0	0	0			0
OCTOBER	FERTILIZER	TOTAL NUMBER PLANTS	0	23	23			15.33
		MEAN HEIGHT	0	22.72	34.03			18.92
		MEAN NUMBER STEMS	0	17.17	49.17			22.11
		PERCENT SURVIVAL	0	92	92			61.33
		MEAN WEIGHT SHOOTS	0	34.14	48.17			27.44
		MEAN WEIGHT ROOTS	0	6.78	7.51			4.76
		TOTAL VOLUNTEERS	0	0	0			0
		MEAN HEIGHT VOLUNTEERS	0	0	0			0
		MEAN STEMS VOLUNTEERS	0	0	0			0
	NO FERTILIZER	TOTAL NUMBER PLANTS	19	8	9			12
		MEAN HEIGHT	28.08	25.34	25.68			27.37
		MEAN NUMBER STEMS	18.32	26.75	24.22			23.1
		PERCENT SURVIVAL	76	32	36			48
		MEAN WEIGHT SHOOTS	9.51	5.71	13.84			9.69
		MEAN WEIGHT ROOTS	2.6	1.86	1.13			1.86
		TOTAL VOLUNTEERS	0	0	0			0
		MEAN HEIGHT VOLUNTEERS	0	0	0			0
		MEAN STEMS VOLUNTEERS	0	0	0			0

SALICORNIA SEEDLINGS

TEST CONDITION 15 & 16

			PLOT REPLICATES					
			1	2	3	4	5	MEAN
MAY	FERTILIZER	TOTAL NUMBER PLANTS	10					10
		MEAN HEIGHT	11.11					11.11
		MEAN NUMBER STEMS	1.4					1.4
		PERCENT SURVIVAL	100					100
		MEAN WEIGHT SHOOTS	0.26					0.26
		MEAN WEIGHT ROOTS	0.1					0.1
	NO FERTILIZER	TOTAL NUMBER PLANTS						
		MEAN HEIGHT						
		MEAN NUMBER STEMS						
		PERCENT SURVIVAL						
		MEAN WEIGHT SHOOTS						
		MEAN WEIGHT ROOTS						
AUGUST	FERTILIZER	TOTAL NUMBER PLANTS	23	20	17			20
		MEAN HEIGHT	17.77	17.51	16.98			17.42
		MEAN NUMBER STEMS	6.7	4.75	10.12			7.19
		PERCENT SURVIVAL	92	80	68			80
		VOLUNTEERS S.PACIFICA	2	6	0			2.67
		VOLUNTEERS S. RUBRA	0	0	0			0
		TOTAL VOLUNTEERS	2	6	0			2.67
		MEAN HEIGHT VOLUNTEERS	12.85	19.13	0			10.66
		MEAN STEMS VOLUNTEERS	6.0	6.17	0			4.06
	NO FERTILIZER	TOTAL NUMBER PLANTS	22	19	11			17.33
		MEAN HEIGHT	15.48	15.43	13.08			14.66
		MEAN NUMBER STEMS	5.5	3.68	3.91			4.36
		PERCENT SURVIVAL	88	76	44			69.33
		VOLUNTEERS S.PACIFICA	4	6	0			3.33
		VOLUNTEERS S. RUBRA	0	0	0			0
		TOTAL VOLUNTEERS	4	6	0			3.33
		MEAN HEIGHT VOLUNTEERS	11.68	11.13	0			7.6
		MEAN STEMS VOLUNTEERS	4.0	2.83	0			2.28
OCTOBER	FERTILIZER	TOTAL NUMBER PLANTS	19	19	17			18.33
		MEAN HEIGHT	25.88	32.71	37.29			31.96
		MEAN NUMBER STEMS	19.79	21.21	42.18			27.73
		PERCENT SURVIVAL	76	76	68			73.33
		MEAN WEIGHT SHOOTS	14.73	45.7	30.22			30.22
		MEAN WEIGHT ROOTS	1.81	3.49	2.65			2.65
		TOTAL VOLUNTEERS	0	0	0			0
		MEAN HEIGHT VOLUNTEERS	0	0	0			0
		MEAN STEMS VOLUNTEERS	0	0	0			0
	NO FERTILIZER	TOTAL NUMBER PLANTS	22	18	8			16
		MEAN HEIGHT	26.85	23.23	26.46			25.51
		MEAN NUMBER STEMS	20.68	15.06	16.38			17.37
		PERCENT SURVIVAL	88	72	32			64
		MEAN WEIGHT SHOOTS	12.0	8.78	12.31			11.03
		MEAN WEIGHT ROOTS	2.44	3.54	1.58			2.52
		TOTAL VOLUNTEERS	0	0	0			0
		MEAN HEIGHT VOLUNTEERS	0	0	0			0
		MEAN STEMS VOLUNTEERS	0	0	0			0

INCLOSURE THREE

SAN FRANCISCO BAY AND ESTUARY DREDGE
DISPOSAL STUDY

MARSH DEVELOPMENT STUDY

PHASE THREE - FINAL INVESTIGATION

Dr. Kenneth Floyde & Dr. Curtis L. Newcombe
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MARSH STUDIES

GROWTH OF INTERTIDAL MARSH PLANTS
ON
DREDGE MATERIAL SUBSTRATE

Prepared For

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ABSTRACT

A section of the north bank of Alameda Creek composed of dredged material was planted with *Spartina foliosa* and *Salicornia pacifica* in the intertidal zone. Growth and survival of these plants as well as changes in benthic organisms and changes in chemical and physical properties of the substrate were monitored over an 18-month period. The results indicated that *S. foliosa* and *S. pacifica* survived and flourished on the barren dredge material substrate although *S. foliosa* plots were not as dense as upcreek stands. A variety of plant starter types were used. The largest plants, *S. foliosa* plugs, had the best rate of growth although predictory growth equations indicated plants derived from seed and other starter types would reach maximal stand density at approximately the same time (26 - 28 months). Volunteer *S. pacifica* plants populated all experimental sites after the first growing season and most of these sites, including unplanted control plots, were as densely populated with *S. pacifica* as older parts of Alameda Creek. No fertilizer or elevational effects on growth of *S. foliosa* or *S. pacifica* were observed. Benthic analysis indicated increases in mollusk, annelid worms, and insect larvae in sampled sites. Chemical analysis of the substrate indicated increases in iron, zinc, lead and phosphate while the only physical change of the substrate noted was an increase in compression strength and an increase in the number of particles in the 32 - 500 μ range. The latter chemical and physical changes were thought to benefit plant growth.

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GROWTH OF INTERTIDAL MARSH PLANTS ON DREDGE MATERIAL SUBSTRATE

INTRODUCTION

The innovative concept of creating habitats on barren dredge material has been demonstrated to be feasible along the Atlantic Coast. Habitats have been created by the extensive use of selective vegetation upon both islands created of dredge material (Parnell and Soots, 1974) and upon dredged material deposited along waterways (Woodhouse *et al.*, 1974; Dunstan *et al.*, 1975). The extensive maritime traffic in San Francisco Bay and the resultant dredging to accommodate this traffic has produced both the dredged materials and the opportunity to biologically repopulate dredged material. To determine whether marsh creation was feasible in the San Francisco Bay Area, the Corps of Engineers initiated a marsh creation project on dredged material deposited intertidally near the mouth of Alameda Creek which empties into San Francisco Bay. This report summarizes the observations over an 18-month monitoring period, from May 1974 to October 1975, which have been made on the marsh created on dredged material. The early results describing the experimental conditions and the initial growth of *Spartina foliosa* and *Salicornia pacifica* during the period May 1974 - December 1974 have been reported previously (Newcombe and Pride, 1975).

MATERIALS AND METHODS

Experimental Design

Approximately 500 meters of dredged material which composed a section of the intertidal north bank of Alameda Creek was sloped toward the Creek for test purposes. Experimental plots were staked and arranged such that each of 30 experimental areas parallel with the shore contained three 5 M^2 plots arranged perpendicularly and labeled "A", "B" and "C". Each plot was separated by 5 M^2 from other plots. The elevation of the higher "A" plots were designed to be 9 ft MLLW, while the "B" and "C" plots were to be at 7 ft MLLW. The MHHW for this area is 8 ft and the mean sea level (MSL) elevation is 4.3 ft MLLW.

The purpose of plots was to provide a statistical mechanism for monitoring the growth and survival of *Salicornia pacifica* and *Spartina foliosa* established on dredged material. The growth parameters of interest were starter type, fertilizer effects and time for growth. The higher "A" plots contained *S. pacifica* and were established by three starter types (with control plots), each in three replicates. These 12 plots were duplicated to examine fertilizer effects and the 24 "A" plots were randomized for experimental treatment. The lower "B" and "C" plots contained *S. foliosa* established as five starter types (and control plots), each in five replicates. These 30 plots were

duplicated to examine fertilizer effects. Due to a grading irregularity, two plots for seeds were eliminated but the remaining plots were randomized for experimental treatment. The actual experimental design and the initial and final elevations of each plot is shown in Table I.

Statistical Analysis

Growth was analyzed by a repeated measure design using the three-way analysis of variance program adapted for the Hewlett-Packard 9830 computer. A particular growth parameter was analyzed with regard to starter type, fertilizer, and time effects. The datum entered for any growth parameter was the mean obtained from all plants in that particular plot. The F statistic for the growth parameters is presented in Tables and the standard error for each mean on an indicated graph also is presented in accompanying tables. Elevational effects and growth estimates were analyzed by a linear regression program adapted for the 9830 computer. Skewness of data derived through soil sampling "grabs" for the chemical and physical analyses was represented by the coefficient of variation (cv), $\sigma/\bar{x} \times 100$.

Plant Material

The perennials *Spartina foliosa* Trin. (cordgrass) and *Salicornia pacifica* Standl. (pickleweed) were planted in the experimental plots. *S. pacifica* and the annual *Salicornia rubra* invaded the plots via seed

TABLE I.

*Elevation and Treatment Plan of Alameda Plots**

Plot	Starter Type	Fertilizer	Initial Elevation	1975 Elevation
41-00A	Shoots	F	9.0	8.6
41-25A	Cuttings	F	9.3	8.8
B	Plugs	F	9.1	8.6
C	Plugs	F	6.6	6.6
41-50A	Control	U	9.3	9.1
B	Seeds	F	8.4	7.9
C	Seedlings	F	6.0	6.1
41-75A	Cuttings	U	9.8	9.4
B	(R) Cuttings	U	8.7	8.1
C	(R) Cuttings	F	6.1	6.2
42-00B	Control	U	8.8	8.3
C	(D) Cuttings	F	6.9	6.6
42-25A	Seedlings	F	9.6	9.3
B	Cuttings	U	8.4	8.0
C	Plugs	F	6.7	6.6
42-50A	Cuttings	F	9.5	9.2
B	Seedlings	U	8.9	8.1
C	Seedlings	F	6.3	6.4
42-75A	Seedlings	U	9.1	8.7
B	Control	U	8.1	7.9
C	(D) Cuttings	U	7.5	6.9
43-00A	Control	F	9.2	9.0
B	Seed	U	8.3	7.9
C	Plugs	U	6.8	6.6
43-25B	Seed	U	8.0	7.6
C	Plugs	U	6.6	6.5
43-50A	Control	F	10.2	9.0
B	Seedlings	F	8.1	7.7
C	Plugs	U	6.8	6.5
43-75A	Shoots	F	9.3	9.0
B	Control	F	7.7	7.3
C	Seedlings	U	7.0	5.9

(Continued)

TABLE I. (Continued)

Plot	Starter Type	Fertilizer	Initial Elevation	1975 Elevation
44-00A	Seedlings	U	9.3	8.9
B	(D) Cuttings	F	7.5	7.2
C	(D) Cuttings	F	6.7	5.9
44-25B	(D) Cuttings	F	7.2	8.0
C	Plugs	U	6.4	5.9
44-50B	(R) Cuttings	F	7.5	7.1
C	(R) Cuttings	U	6.8	6.4
44-75B	(R) Cuttings	U	7.7	7.2
C	(R) Cuttings	F	6.5	6.5
45-00A	Shoots	U	9.6	9.2
B	Control	F	8.1	7.8
C	(D) Cuttings	U	6.9	6.6
45-25A	Seedlings	F	11.5	10.8
B	Control	F	8.1	7.9
45-50A	Control	F	9.7	9.1
B	(R) Cuttings	F	7.9	7.7
C	Seed	F	7.2	6.8
45-75A	Cuttings	U	10.0	9.8
B	(R) Cuttings	F	8.4	8.0
C	Seed	F	7.2	6.9
46-00A	Control	U	10.4	10.0
B	Seedlings	U	8.4	7.9
C	Control	U	6.8	6.5
46-25B	(D) Cuttings	F	7.9	7.4
C	Control	U	6.8	6.4
46-50A	Shoots	U	10.0	9.5
B	(R) Cuttings	U	8.0	7.7
C	Seedlings	F	7.4	7.5
46-75A	Seedlings	U	8.9	8.6
B	Control	U	8.9	7.3
C	Seedlings	U	7.2	7.3

(Continued)

TABLE I. (Continued)

Plot	Starter Type	Fertilizer	Initial Elevation	1975 Elevation
47-00A	Cuttings	U	11.0	10.4
B	Seedlings	F	9.5	8.9
C	Seed	U	7.2	6.9
47-25A	Shoots	U	10.8	10.4
B	Plugs	U	7.9	7.7
C	Seed	U	6.8	6.6
47-50A	Control	U	9.8	9.1
B	Seeds	F	7.7	7.5
C	(D) Cuttings	U	6.3	6.4
47-75A	Cuttings	F	10.8	10.1
B	Plugs	F	7.6	7.3
C	(D) Cuttings	U	6.4	5.9
48-00A	Seedlings	F	11.0	10.4
B	Seedlings	U	7.0	7.1
C	Control	F	6.8	6.7
48-25A	Shoots	F	11.5	10.7
B	(R) Cuttings	U	7.6	7.4
C	Plugs	F	7.0	6.7

*F = Fertilized;
U = Unfertilized;
R = Robust;
D = Dwarf.

during the second growing season. Growth analyses were performed on all three species.

Starter Types

Seeds of *S. foliosa* were collected from a cordgrass stand on the Petaluma River in the fall of 1973 and maintained in brackish water (2% salinity) at 4 C until May 1974. They were tested for viability during the storage period (80% viability). One liter of seeds (~ 2500 viable seeds) were hand spread on a plot and raked in to minimize dislocation by wave and tidal action. Seedlings of *S. foliosa* were started in 10 × 10 cm peat pots containing an equal sand-dredge material mixture. Each peat pot contained one plant that was approximately four months old when the peat pot was placed in the appropriate plot. Plugs of *S. foliosa* were prepared by removing the mature plants plus roots and soil as 5 in. (12.7 cm) cubes. These were removed prior to planting from a cordgrass stand on the Petaluma River composed of tall healthy plants and consequently labeled "robust". The plugs were placed in appropriately-sized holes and packed with material removed from the hole.

The *S. foliosa* robust cuttings were prepared by gently teasing small shoots from larger "robust" plants, dipping the root of the plant in rooting hormones and placing the sprig in a peat pot. The cuttings

were a composite of plants that received a variety of rooting hormones which apparently had no effect as measured by surface growth (Mason, 1973). These cuttings were prepared in September 1973 from plants obtained at the Petaluma River. "Dwarf" cuttings were prepared by teasing small sprigs from small *S. foliosa* plants located at the mouth of Alameda Creek. Dwarf spartina was a suspected genetic variant whose diminished growth also could be attributed to nutritive deprivation at the higher elevations.

Pickleweed seedlings were started from seed germinated in October 1973 and contained one plant per peat pot in an equal sand-dredge material mixture. *S. pacifica* cuttings were prepared by slicing the plant stem such that at least one inch "pickles" were obtained. This material was freshly cut and hence unrooted. Rooted cuttings of *S. pacifica* (shoots) were prepared by removing 4 - 6 inches of the terminal end of an upright branch in October 1973, dipping the plant in rooting hormone, and placing it in a 50-50 sand-dredge material mixture. All plants in peat pots were maintained in large tanks and were inundated daily for 8 hr with San Francisco Bay water whose salinity range was about 10 - 15 ppt.

Growth Measurements

The height of a *S. foliosa* plant was the distance from the soil line to the top of the highest culm and the height of a *S. pacifica*

plant was the distance from the soil line to the top of the longest stem. A "plant" of *S. foliosa* was difficult to assess at times but was defined arbitrarily as one at least 15 cm from its nearest neighbor. *S. pacifica* stems were enumerated by counting the stems on a typical branch and multiplying this number by the number of branches on that particular plant. Rhizome migration was measured as the distance from the center of an established plant to the last visible shoot. These measurements were made in February 1976 and represent a year's growth since shoots from rhizomes were absent in February 1975. Dry weights were obtained on one visually representative plant from every plot following its removal to the Point San Pablo Laboratory where the soil was removed with the aid of water and it was dried 12 hrs at 105 C before weighing.

Benthic Analysis

Three grabs of 256 cm^2 (16 × 16 × 7.6 cm depth) were made at each sampling site. The material was returned to the Laboratory where standard methods were used to wash, sort, preserve, and identify the macroscopic forms.

Chemical Analysis of Soils

Soil samples for chemical analysis were collected with a coring device constructed with polyvinyl cylinder that was equipped with a

vinyl stopper. Cores of soil (30 cm) were removed, pushed onto aluminum foil for storage, and maintained at 4 C in the laboratory. Extracts were prepared from the core material according to Walsh (1970) and heavy metal determinations were performed in triplicate as recommended by Standard Methods (1971).

Physical Analysis of Soil

The soil obtained by coring was analyzed for particle size by the method of Emery (1938). Compression shear strength, which measured the cohesion of a sediment, was performed as recommended by Pestrong (1965) by a method that records the compression of the core following the loading of the soil core with increased weights of water.

Fertilizer

Fertilizer ("Formula 48") was hand spread over plots to be fertilized. Approximately 3 lbs/100 ft^2 was used. The fertilizer contained: 8% nitrogen, 4% phosphate, 4% sulphur, 1% iron, 6% calcium, 0.1% zinc, and 0.1% magnesium.

RESULTS

That *Spartina foliosa* and *Salicornia pacifica* planted on dredge material at Alameda Creek survived is demonstrated in the photograph (Fig. 1.) depicting the planting site 15 months after planting. The experimental plots are delineated by stakes and the variable nature of the vegetation in the plots as well as the sloping of the site also is visible in the photograph. The quantitative description of plant growth, benthic repopulation, and physical changes in the individual plots is described in the remainder of the "Results" section below.

Effect of Fertilizer

An initial concern was the effect of fertilizer on the growth of *Spartina foliosa* and *Salicornia pacifica* and this concern was reflected in the equal division of the site into either fertilized or unfertilized plots. Factorial analysis of variance indicated that no effect of fertilizer was evident on survival or growth of *Spartina foliosa* and *Salicornia pacifica* in this particular study (Table II). Fertilizer interactions also were not significant. The results depicting the effect of fertilizer on the number of *Spartina foliosa* plants is presented in Fig. 2. The data presented in Fig. 2 graphically illustrates the

FIGURE 1. View of Alameda Creek experimental site.

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TABLE II.

Statistical Analysis of Fertilizer Effects on Growth

Species	Growth Parameter	F-Ratio*	P(F) > F	Comment
S. foliosa	Plants	0.006	0.00	Not significant
"	Culms	1.298	0.25	Not significant
"	Height	2.300	0.12	Not significant
S. pacifica	Plants	4.010	0.04	Not significant
"	Stems	0.280	0.00	Not significant
"	Height	0.320	0.00	Not significant

*Derived from a factorial analysis of variance.

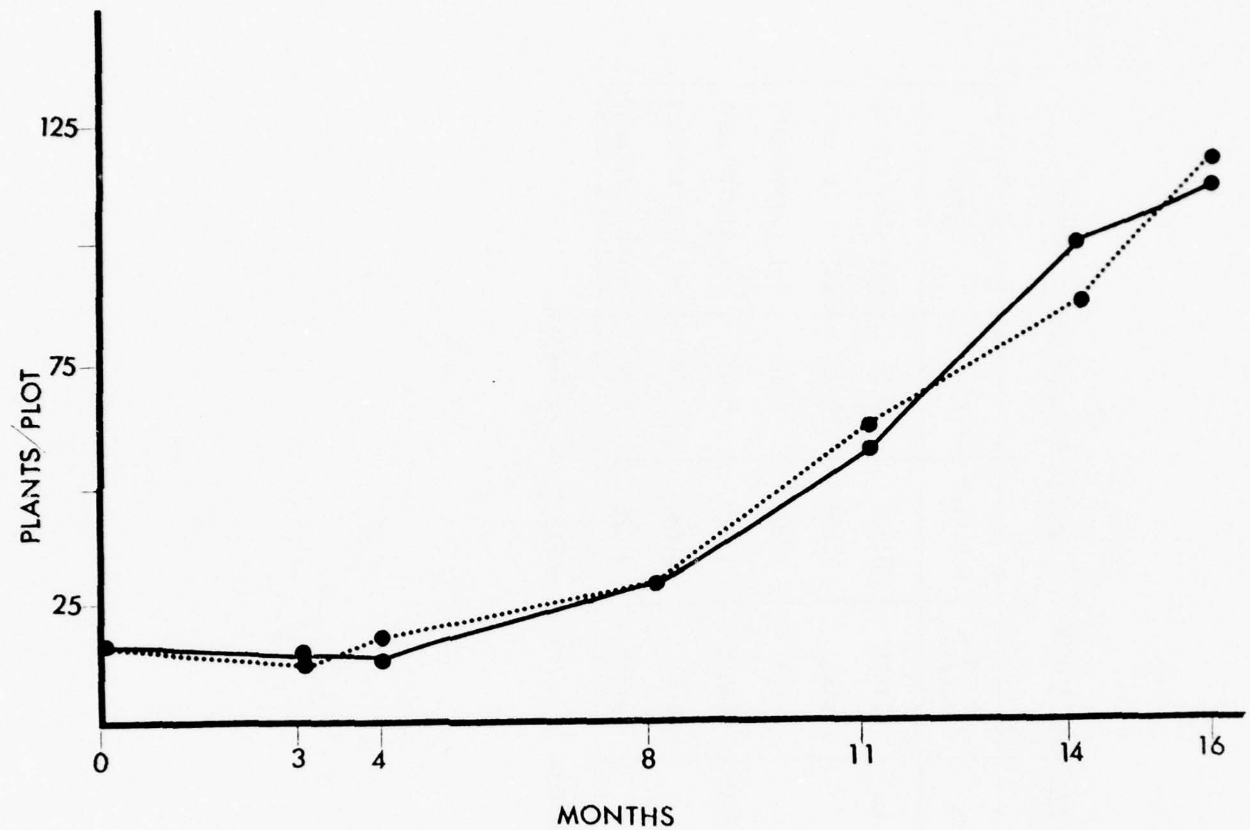

FIGURE 2. *Effect of fertilizer on the number of S. foliosa plants. Symbols: fertilized plots (——), unfertilized plots (...).*

similarity obtained with all starter types in fertilized and unfertilized plots. While these results indicated no effect of fertilizer on the growth or survival of *S. foliosa* and *S. pacifica* in this particular study, the conclusion cannot be made that fertilizer is without effect on growth of these plants. The method of fertilization (hand spreading of crystalline material only once) probably was inadequate to permit any long-lasting fertilizer effect. Since no fertilizer effect was discernable, the fertilized and unfertilized plots of each starter type were combined to increase the power of the statistical analysis of plant growth.

Growth of *Spartina foliosa*

The lower elevational plots were planted with five different starter types of *Spartina foliosa* and the growth of each starter type was monitored approximately once each season. Growth was measured by determining the average height of *S. foliosa* culms (Fig. 3), number of culms (Fig. 4), number of plants (Fig. 5), and dry weight of shoots (Fig. 6) and roots (Fig. 7). The standard deviation and standard error of each mean presented in Figures 3-5 are listed in Table III. The values of control plots were artificially low due to the absence of plants in some plots and to the fact that the repeated measure design incorporated this zero data in its computation of means and variance.

TABLE III.

Means and Variance of Growth Measurements as a Function of Time and Starter Type

Sampling Time	Starter Type	Height			Culms/Plant			Plants/Plot		
		$\bar{x}$	σ	Sx	$\bar{x}$	σ	Sx	$\bar{x}$	σ	Sx
2	Seeds	9.34	1.85	0.23	1.30	0.47	0.06	17	11.0	1.42
Aug. '74	Seedlings	14.20	1.90	0.19	2.87	0.70	0.07	14	4.0	0.44
	(R) Cuttings	15.80	3.01	0.30	1.80	0.61	0.06	8	3.0	0.36
	(D) Cuttings	14.60	2.78	0.28	2.75	0.85	0.08	18	3.8	0.39
	Plug	22.3	4.64	0.46	0.27	0.60	0.06	22	2.9	2.90
3	Seeds	17.05	1.80	0.23	2.51	0.60	0.12	32	27.0	3.47
Oct. '74	Seedlings	20.72	2.77	0.28	7.07	1.41	0.14	13	4.0	0.44
	(R) Cuttings	25.82	3.30	0.33	3.52	1.18	0.12	7	5.0	0.57
	(D) Cuttings	18.32	2.89	0.29	5.57	1.27	0.13	17	4.0	0.40
	Plugs	26.72	3.79	0.38	6.58	0.76	1.52	20	3.0	0.35
4	Seeds	7.30	1.50	0.38	2.89	0.68	0.08	40	21.0	2.72
Feb. '75	Seedlings	8.22	3.18	0.22	4.49	1.96	0.20	40	18.0	1.88
	(R) Cuttings	11.46	5.09	0.51	2.86	1.38	0.14	11	13.0	1.31
	(D) Cuttings	6.54	1.58	0.16	3.94	1.06	0.11	43	24.0	2.41
	Plugs	16.93	4.33	0.43	5.84	2.13	0.21	42	12.0	1.22

(Continued)

Table III. (Continued)

Sampling Time	Starter Type	Height			Culms/Plant			Plants/Plot		
		$\bar{x}$	σ	Sx	$\bar{x}$	σ	Sx	$\bar{x}$	σ	Sx
5	Seeds	13.25	3.53	0.44	2.36	0.36	0.05	67	45.0	5.63
May '75	Seedlings	13.71	2.15	0.21	3.28	0.77	0.08	77	41.0	4.16
	(R) Cuttings	15.12	5.88	0.59	1.95	1.09	0.11	18	22.0	2.29
	(D) Cuttings	11.99	2.23	0.22	2.48	0.52	0.05	96	54.0	5.46
	Plugs	17.82	2.35	0.24	3.48	0.78	0.08	101	44.0	4.47
6	Seeds	26.05	3.66	0.46	6.35	1.37	0.17	100	48.0	6.11
Aug. '75	Seedlings	26.43	4.37	0.44	7.43	3.90	0.39	107	49.0	4.99
	(R) Cuttings	23.78	13.31	1.33	3.46	2.26	0.23	25	36.0	3.63
	(D) Cuttings	28.10	5.35	0.53	6.88	2.77	0.28	156	98.0	9.85
	Plugs	30.42	5.25	0.52	6.07	2.26	0.23	171	76.0	7.69
7	Seeds	23.35	1.83	0.23	12.20	2.63	0.33	107	57.0	7.16
Oct. '75	Seedlings	22.84	3.55	0.36	11.56	2.71	0.27	140	85.0	8.51
	(R) Cuttings	23.05	10.23	1.02	6.30	2.43	0.24	26	33.0	3.34
	(D) Cuttings	24.40	6.28	0.63	10.99	3.34	0.33	195	93.0	9.33
	Plugs	26.50	4.99	0.50	9.88	2.58	0.26	223	108.0	10.86

The height of all spartina starter types was essentially equivalent after two growing seasons (Fig. 3) and, with the exception of plants started from seed and dwarf cuttings, almost equivalent in height by September of the first growing season. The average height of all starter types decreased during the winter due to loss of large senescent culms and the inclusion of late-growing stems in the analysis. A transplantation effect was noticed in that plants started from cuttings and plugs were shorter at the first measuring period (August 1974) than when measured originally in May 1974. Again, this decrease in height was probably at the expense of senescent culms present in the original material. The ultimate average height reached by all starter types (25 - 30 cm) on the Alameda dredge material was considerably less than that observed for spartina plants upstream (75 cm), although some individual plants were 75 cm tall.

With the exception of spartina plants derived from robust cuttings, the number of culms per plant was essentially equivalent after two growing seasons (Fig. 4). The number of culms per plant increased in all starter types during the first growing season, decreased during the spring (1975) and subsequently increased during the summer-fall growing season. The considerable variation in the number of culms observed during the fall 1974 monitoring probably reflected the initial biomass of each starter type. The starter types with the larger initial biomass produced more culms. The reduced number of culms obtained with robust cuttings was

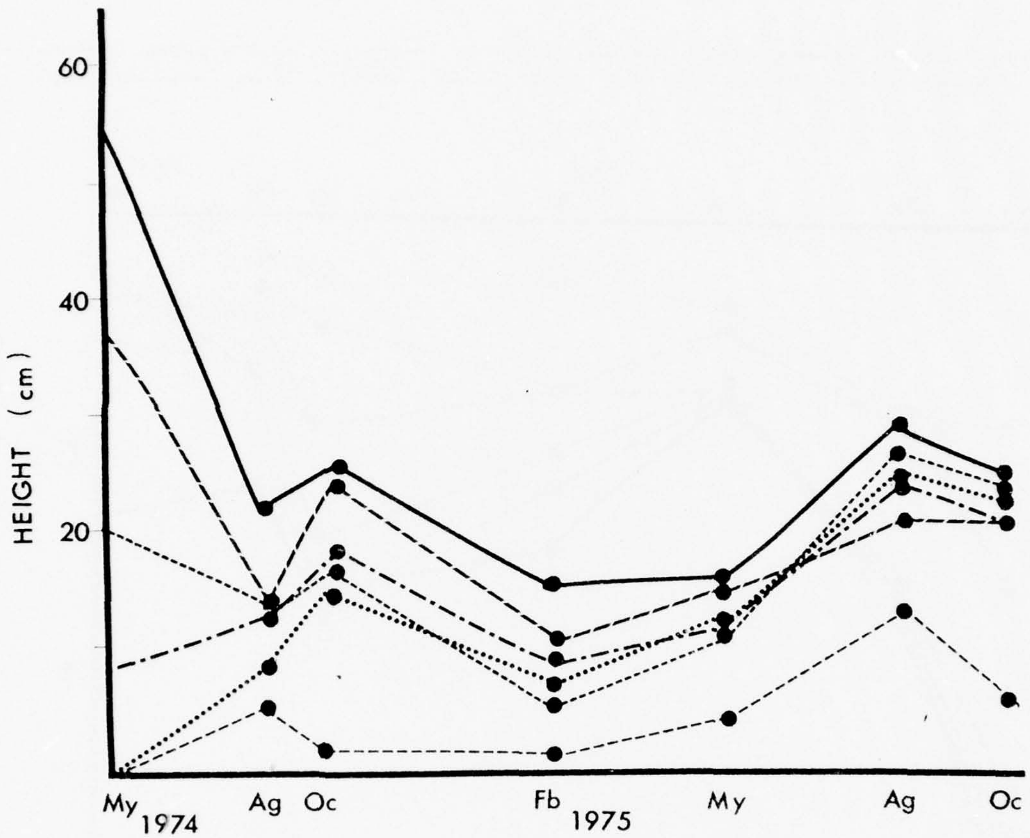

FIGURE 3. Culm height of S. foliosa starter types. Symbols: seeds (••••••), robust cuttings (▬ ▬ ▬), dwarf cuttings (- - - - -), seedlings (▬ · ▬), plug (▬▬▬), control (– – – –).

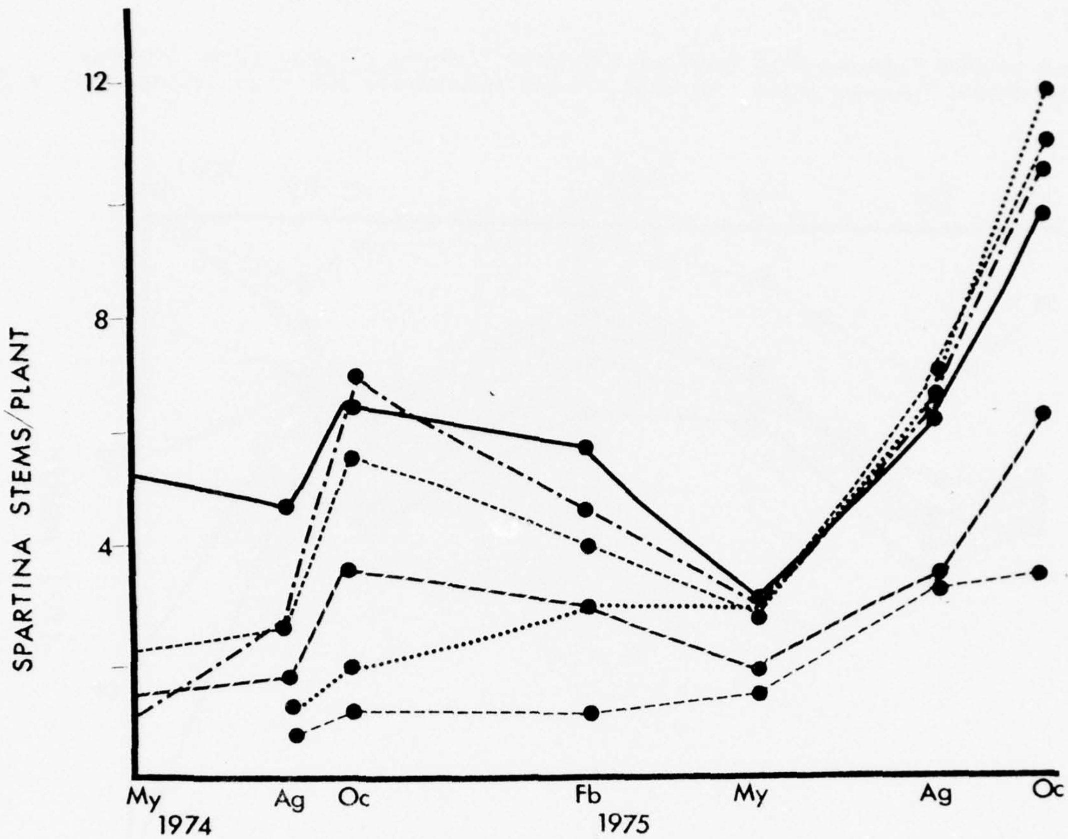

FIGURE 4. Culms per plant of S. *foliosa* starter type. Symbols: seeds (••••••), robust cuttings (— — —), dwarf cuttings (------), seedling (—·—), plugs (▬▬), control (----).

unexpected and may be a reflection of the poorer proliferation rate observed with robust cuttings as described below.

The increase in spartina plants derived from each starter type is depicted in Fig. 5. A statistically significant difference existed among the various starter types (Table III). The increased number of plants in plots derived from plugs was due in part to the higher survival rate and to a greater biomass. Both factors would increase the potential for generating additional plants in a plot through rhizoid migration. An additional factor may be the amount of winter root growth (described in the following section) since all plots of starter types, except robust cuttings, had approximately the same average number of plants by February 1975. Individual plots heavily seeded with spartina produced as many plants as some plots derived from plugs.

The variability of plants/plot derived from seeds does not permit a valid comparison with other starter types. If, perchance, twice the amount of seeds had been used, then the number of plants/plot derived from seed would have compared favorably with the number of plants/plot derived from plugs. In general, the difference between the number of plants derived from plugs and seeds or seedlings is the same as that expected to be derived from the advantage of plugs having an additional growing season. It is interesting to note that approximately 1% of the viable planted seeds resulted in established plants.

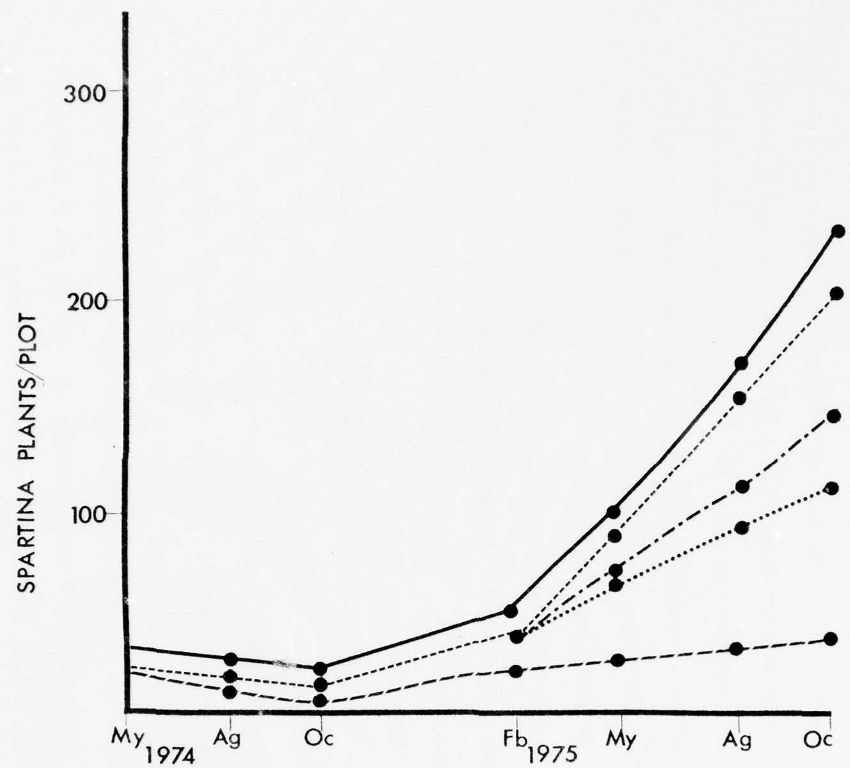

FIGURE 5. Plants per plot of S. foliosa starter type. Symbols: seeds (••••••), robust cuttings (— — —), dwarf cuttings (- - - - -), seedling (· — ·), plugs (———).

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The number of plants derived from robust cuttings was significantly less than that observed for other starter types. Comparisons of root growth of robust with dwarf cuttings offers a possible explanation due to the poorer growth of robust roots, although other explanations are possible.

Examination of the changes in dry weight of roots and shoots revealed several unexpected features of growth. The change in dry weight of shoots is depicted in Fig. 6, and the dry weight changes of roots is shown in Fig. 7. Foremost of interest was the unexpected decrease in root mass during the early spring coincident with the increase in shoot growth. This correlation would be expected if roots were supplying energy and/or nutrition for plant growth. Such a situation would help explain the variable changes observed in growth of plants from different starter types. Also of interest was the increase in root mass that occurred during the winter, at which time net growth of shoots was not occurring. The dry weight of both shoots and roots of the spartina plugs decreased following transplantation but increased during the early summer growing season as did the remainder starter types. In contrast to plugs, the root mass of both cutting types continued to increase following transplantation (Fig. 8). Surprisingly, during the October - February period in which the root mass of all other starter types was increasing, the root mass of the robust cuttings declined. The effect was only temporary and by February the robust cuttings had an almost identical biomass

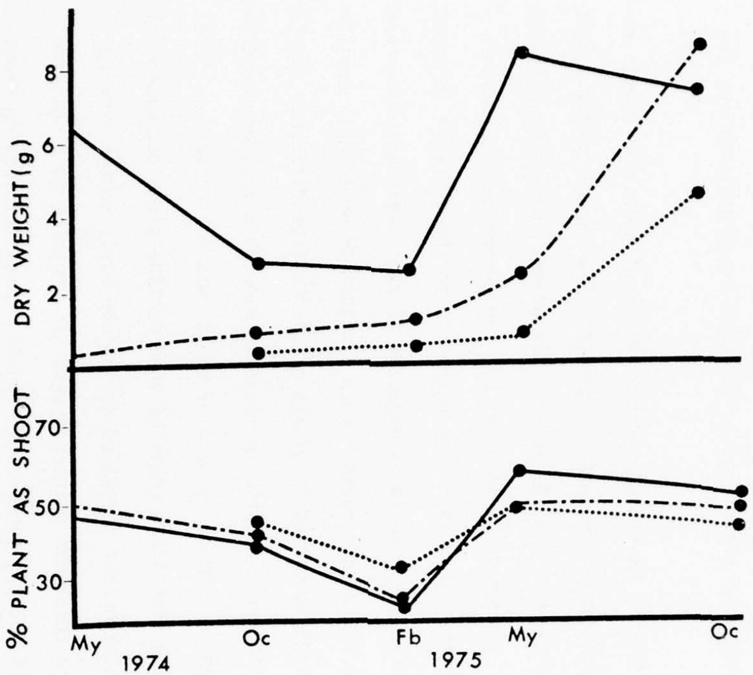

FIGURE 6. *Dry weight analysis of S. foliosa shoot growth. Symbols: seeds (••••••), seedlings (–·–), plugs (——).*

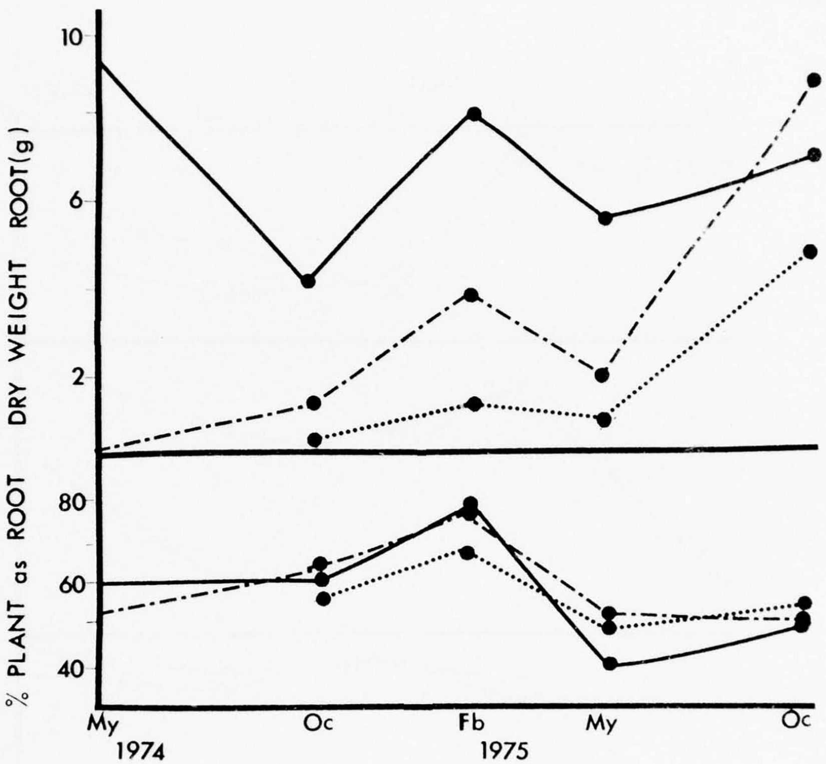

FIGURE 7. Dry weight analysis of S. foliosa root growth. Symbols: seeds (•••••), seedlings (•—•), plugs (▬).

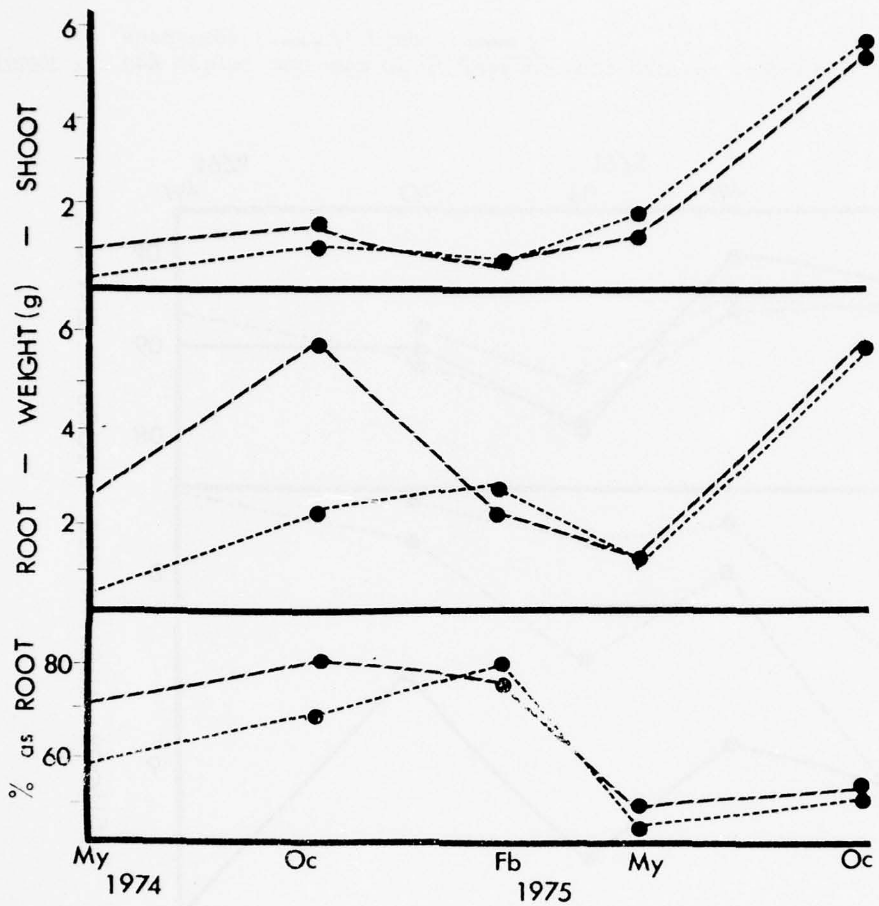

FIGURE 8. Dry weight snalysis of _S. foliosa_ cuttings. Symbols: robust (——), dwarf (----).

increase in both roots and shoots as did the dwarf cuttings. However, the biomass decrease of the robust cutting roots may have influenced rhizome production and caused the significant decrease in plants produced from this starter type. The decline could have resulted from genetic differences, hormonal treatment of the roots, or from nursery storage.

Attempts to correlate the height of a spartina plant with the dry weight of its shoots revealed that dry weight was dependent upon both the height and the number of culms. Surprisingly, if one arbitrarily divided plants into those containing greater than 20 culms with those containing less, a line ($y = 1.3x + 40$) could be constructed by which the dry weight could be estimated from the tallest culm of a plant with more than 20 culms. This correlation, while not absolute, did permit an estimate of a plant's biomass. Roughly, if a plant contained greater than 20 culms, the height of the longest culm above 40 cm was correlated ($r^2 = 0.24$) with its dry weight in grams. For plants with less than 20 culms, the height of the plant was not correlated with its dry weight. The dry weights of roots and culms can be approximated since they were almost equivalent (Fig. 7-8).

Elevational Effects on the Growth and Survival of *Spartina foliosa*

The effect of elevation on various parameters of growth as well as survival of *S. foliosa* was determined through a series of correlational

analyses. The statistical results are presented in Table IV. The effect of elevation on survival was ascertained by correlating the number of plants in each plot at the first monitoring period (August 1974) as a function of the elevation determined in May 1974. This correlation (Fig. 9) included all starter types in order to develop an elevational range and revealed no effect of elevation on survival of *S. foliosa* at these particular elevations at which spartina initially was placed. Another elevational correlation, relating the number of plants which developed by October 1975 is represented in Fig. 10. This study used elevational data on individual plots obtained in December 1975. A cursory comparison of Fig. 10 with Fig. 9 reveals considerable slumping occurred that resulted in most plots residing between 6 and 8 feet MLLW. The effect of elevation on the number of spartina plants was not significant because of a bias introduced by the chance grouping of plots derived from plugs in the 6 - 6.5 MLLW areas. Other analyses indicated no effect of elevation on height of spartina (Fig. 11) or on the number of culms (Fig. 12). It appeared that once a plant was established within the tidal range of the spartina plots at Alameda Creek the growth and subsequent development of that plant was independent of elevational effects (submergence time, nutritional percolation time, etc.).

Another type of elevational study was performed with transects between experimental plots. Four transects were seeded (and raked) with

TABLE IV.

Statistical Analysis of Elevational Correlations Presented in Figures

Figure	R	R^2	S_x	Equation	Comment
10	-.13	.02	7.2	$y = -1.22x + 25$	Not significant
11	-.43	.02	96.0	$y = -6.25x + 5.84$	Not significant
12	.18	.03	4.9	$y = -1.24x + 3.33$	Not significant
13	1.4×10^{-3}	2.1×10^{-6}	3.1	$y = -0.006x + 10.2$	Not significant
17	.94	.89	101.0	$y = 5.44x - 7.9$	Significant
18	.66	.43	21.0	$y = 2.5x - 14.9$	Questionable
19	.51	.26	19.0	$y = 1.5x - 9.9$	Questionable

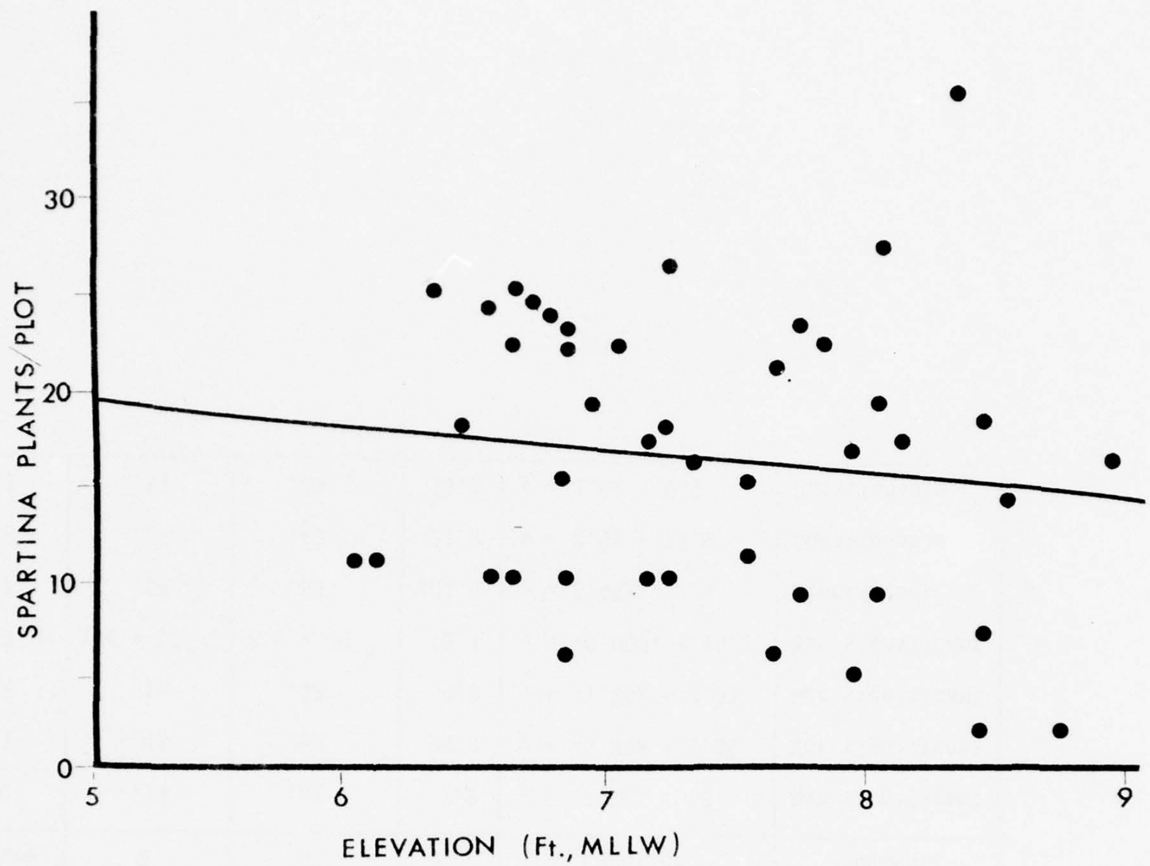

FIGURE 9. Effect of elevation on survival of *S. foliosa*. Each datum represents the mean of an experimental plot located at that particular elevation.

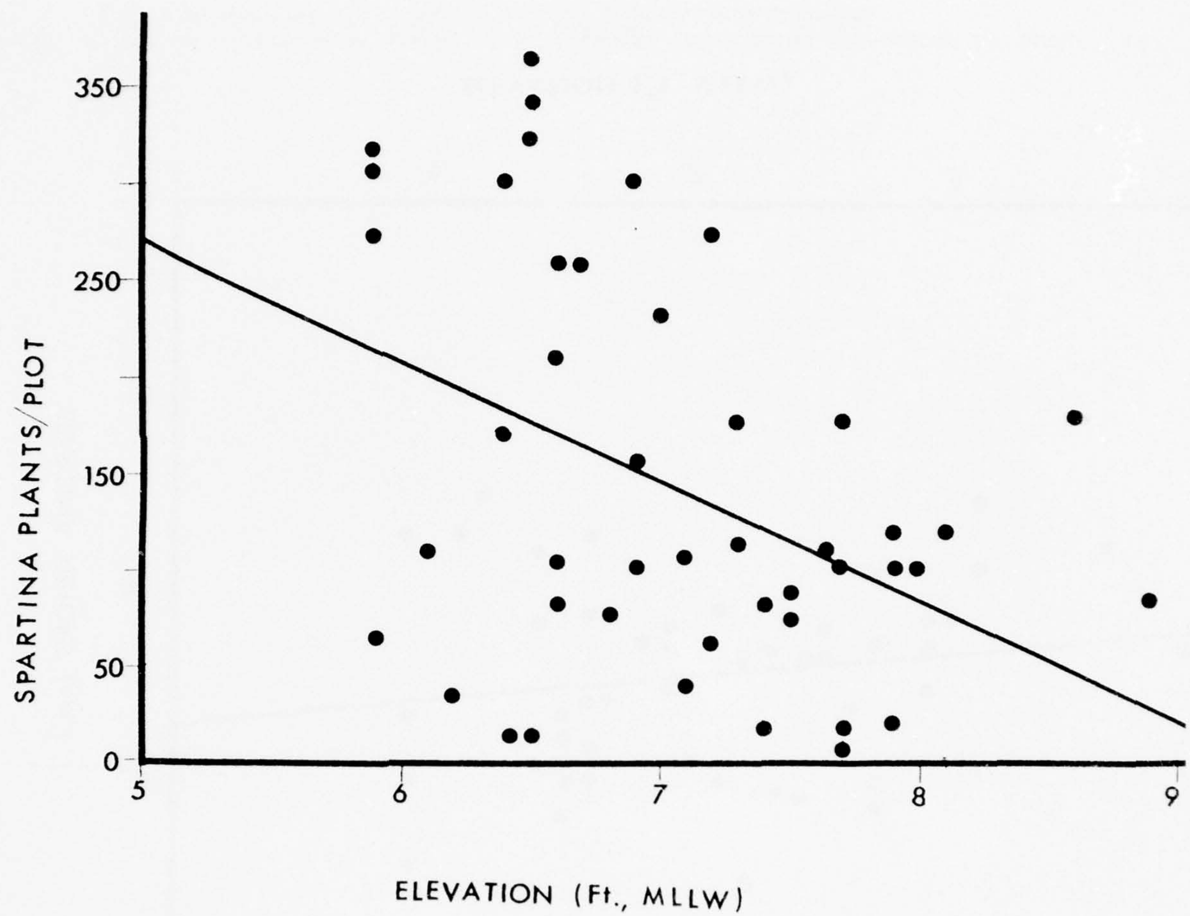

FIGURE 10. Effect of elevation on number of S. foliosa plants. Each datum represents the mean of an experimental plot located at that particular elevation.

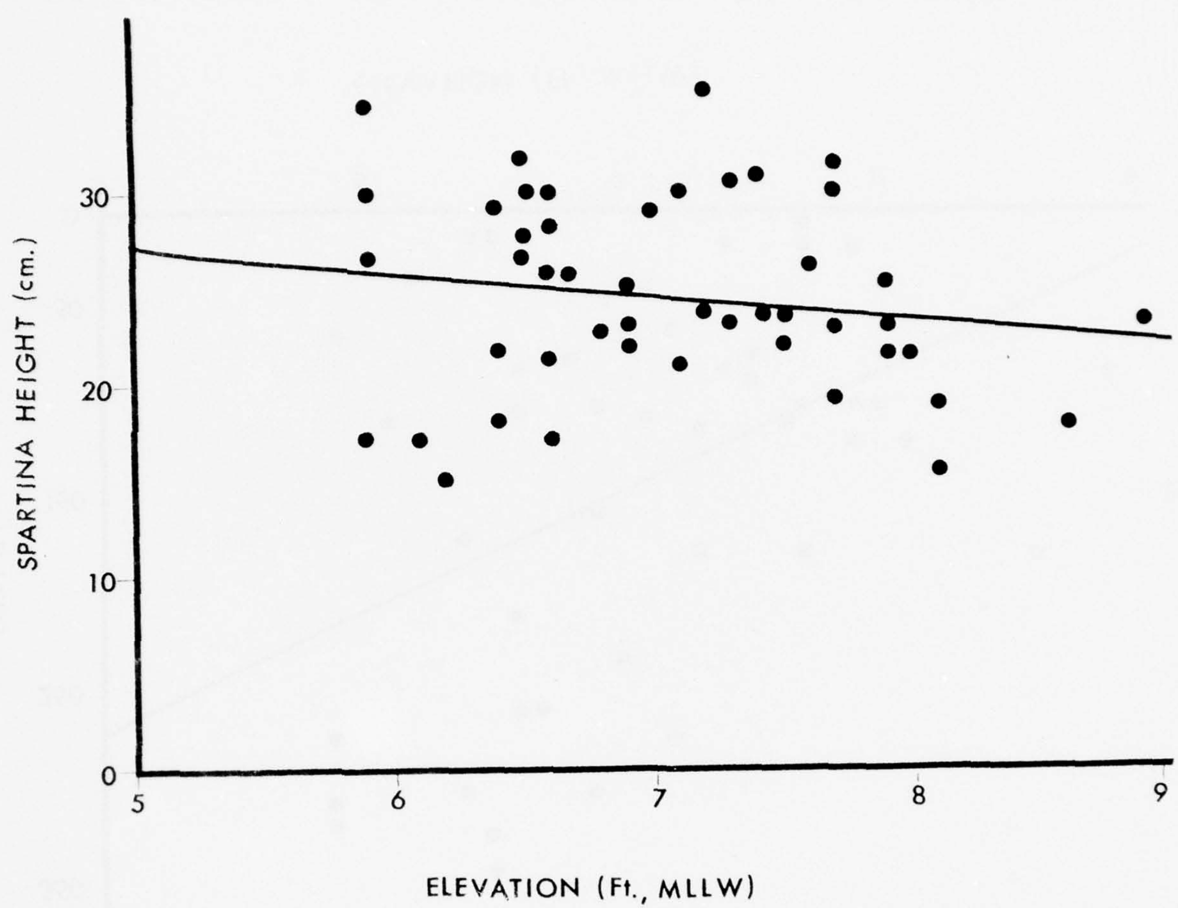

FIGURE 11. Effect of elevation on height of *S. foliosa*. Each datum represents the mean of an experimental plot located at that particular elevation.

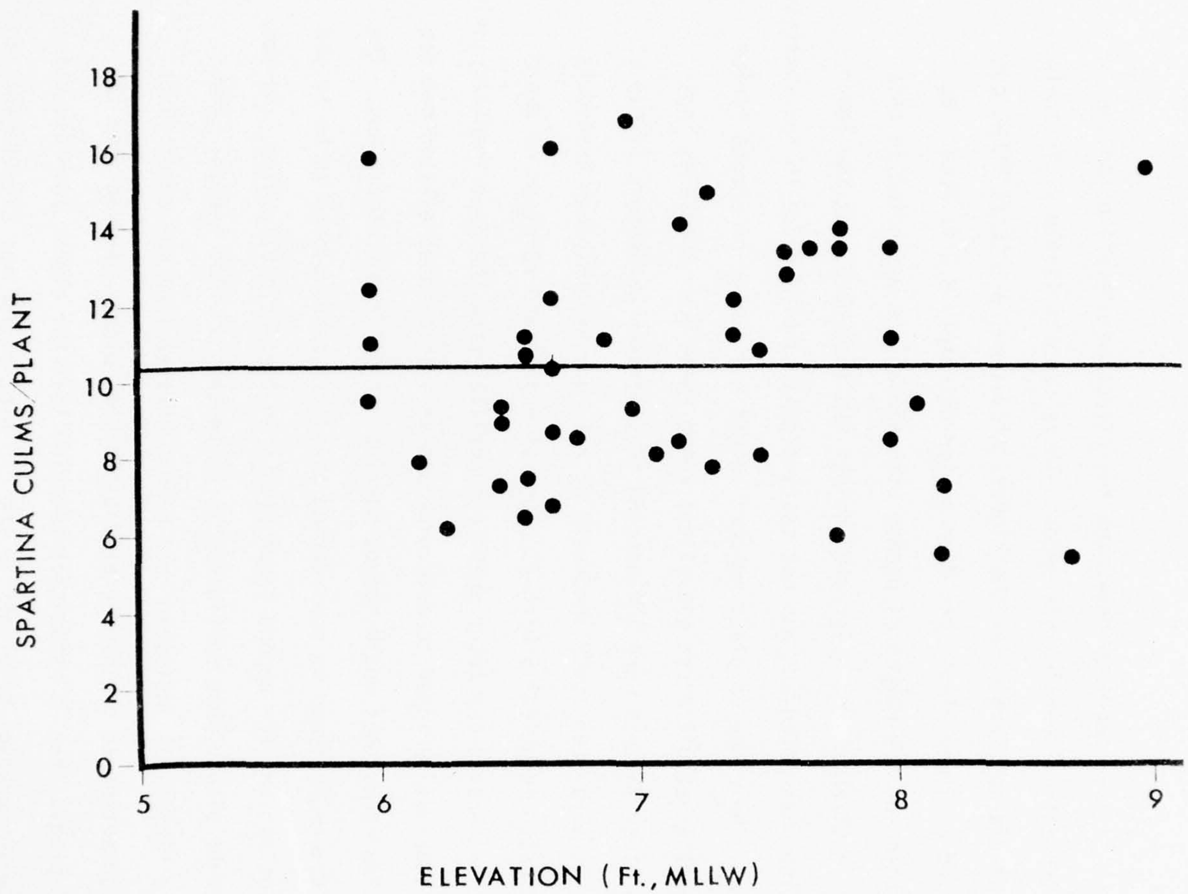

FIGURE 12. Effect of elevation on culms of S. foliosa. Each datum represents the mean of an experimental plot located at that particular elevation.

Spartina foliosa seeds to determine the effect of elevations on the establishment of spartina via seeds. These results (Table V) indicated spartina did not develop at the highest elevation, 8 - 10 ft MLLW, but developed at lower elevations down to approximately 5.5 ft MLLW. No correlation of the number of plants with elevations was noted in this study. A slight trend of greater height and stem number at the lower elevations was noted but was not statistically analyzed due to the sparsity of data. The range of plant number, height and number of shoots varied considerably at different elevations among these four transects indicating other factors were influencing these growth parameters (Table V).

In a related study conducted by H.T. Harvey, thirteen transects were planted identically with 22 plugs of robust and 22 plugs of dwarf *S. foliosa* spaced one meter apart and parallel with the experimental plots. This study was designed to determine whether differences existed between these two forms that would affect survival at different elevations. The results were analyzed by considering the first seven plants to be in the "A" plot region, the second seven plants in the "B" plot region, and the last eight plants were considered to be in the "C" plot region. The results (Table VI) indicated that plants derived from the dwarf plugs survived better at the higher elevations than plants derived from the robust plugs. The "t" statistic revealed that the almost two-fold difference in survival of plants in the "A" plot region was significant at the 95% level of confidence but not at the 99% level. Even though dwarf

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TABLE V.

Characteristics of S. foliosa Derived from Seed in Transects

Location	Plant Number	Height (cm)	Number Culms
Upper A	0		
Mid A	0		
Lower A	0		
Upper B	16	17.5	8.0
Mid B	29	21.8	7.8
Lower B	55	31.0	12.6
Upper C	19	27.0	11.3
Mid C	26	30.6	12.8
Lower C	52	32.7	15.3

TABLE VI.

Survival of Dwarf and Robust Plugs in Transects

Location	Robust Plugs			Dwarf Plugs		
	Plants*	σ	Survival	Plants*	σ	Survival
A Plot	2.6	0.3	37 %	4.4	1.3	63 %
B Plot	3.7	2.4	53 %	5.5	1.3	79 %
C Plot	1.8	1.5	23 %	2.4	1.8	30 %

*Number of survivals

plugs originated from higher elevations, no explanation was obvious to explain any elevational survival advantage for this form except that they were "physiologically adapted" for growth at the higher elevation. The survival of plugs derived from the two forms were not significantly different at the lower elevations. The report describing this particular study, performed by Dr. Harvey, is enclosed.

Stand Density

One desirable consequence of monitoring spartina growth is to use this information to predict the time for experimental plots to become mature stands of *S. foliosa*. Unfortunately, spartina plants growing in mature dense stands, unlike in an experimental plot, are impossible to delineate. To circumvent this problem, several growth characteristics were measured on mature, dense stands of spartina growing along Alameda Creek and were expressed in terms of area (M^2). The appropriate corresponding experimental plot data were derived by considering the number of plants/25 M^2. The summarized data (Table VII) indicated that the number of culms/M^2 in the experimental plots had increased on the average 14 fold. However, culms/M^2 in the "best" plot was not equivalent to that observed for a typical stand of robust spartina. The criterion of shoot dry weight also indicated that the experimental plots had not reached maturity. However, the yearly rate of increase of both growth

TABLE VII.

Comparison of Density of Spartina Stands on Alameda Creek

Characteristic/M^2	MATURE STANDS		EXPERIMENTAL SITE					
	Dwarf	Robust	Average Plot			Best Plot (44-00 C)		
	(Downcreek)	(Upcreek)	Oct. '74	Oct. '75	Change Δ	Oct. '74	Oct. '75	Change Δ
Inflorescence	51	138						
Culm &/or Shoots	5940	434	3.4	59	17x	6.00	200	33x
Mean Height (cm)	37	75		26			30	
Dry Wt. Shoots (g)	182	923	1.0	36	36x	0.24	56	233x

characteristics indicated that maximal stand density may be only a growing season away.

To further refine the estimated time to establish maximal stand density, predicatory equations were derived describing the proliferation of spartina culms/M^2 for each starter type. The data for each starter type at each monitoring period was obtained from the culms/plant and plants/25 M^2 plot means listed in Table VIII. The equations (Table VIII) were used to derive the time necessary to obtain 450 culms/M^2 from each starter type. The surprising result from these calculations (Table VIII) was that maximal stand density, as defined by 450 culms/M^2 will be reached by all starter types listed in Table VIII at approximately the same time (Fall, 1976). The independence of starter type on establishment of stand density was unexpected, as was the similarity of the first derivatives describing culm proliferation ($\bar{y} = 0.236\ e^t$). Presumably, when these 450 culms reach maturity their dry weight would compare favorably with the dry weight of the mature Alameda stand. A longer repopulation time would be expected for plots with fewer plants (control and robust cutting plots) and for the bare interplot area. However, rhizoid migration rates of 0.64 M/yr for plants derived from plugs, 0.95 M/yr for dwarf cuttings, 0.30 M/yr for plants started from seed, and 0.48 M/yr for plants derived from seedlings, would indicate denuded areas would be repopulated following two additional growing seasons.

TABLE VIII.

Equations Describing Culm Proliferation

Starter Type	Predictory Equation	r	Time (450 culms/M^2)
Seeds	$\ln y = 0.245x - 0.48$	.97	27 months (Aug. 76)
Seedlings	$\ln y = 0.238x - 0.59$	.98	28 months (Sept. 76)
Dwarf cuttings	$\ln y = 0.250x - 0.90$	.97	28 months (Sept. 76)
Plugs	$\ln y = 0.212x + 0.57$	.97	26 months (July 76)

y = number of culms/M^2

x = months from initial planting

r = coefficient of correlation

Growth of *Salicornia pacifica*

The analysis of growth of *S. pacifica* was complicated by the inclusion of numerous volunteer plants that invaded the plots during the 1975 growing season. The combination of varied numbers of young plants suddenly being included in the analysis with one year old plants considerably skewed the data and made valid interpretations hazardous and somewhat meaningless. Nevertheless, the growth of the various starter types was analyzed. *S. pacifica* started from seedlings survived better than other starter types (Fig. 13). The seedling plots also yielded the most plants but again no valid interpretation was possible because of the innumerable volunteer plants. Even the unplanted control plots in October 1975 had more plants than plots established with cuttings. Salicornia plants established by cuttings had the greatest average number of stems (Fig. 14), which probably reflected the greatest number of older plants and the fewest young volunteers. These factors also probably were responsible for salicornia plots derived from cuttings having the greatest height (Fig. 15).

The dry weight analysis of *S. pacifica* was interesting and revealed an unexpected correlation. The dry weights of all *S. pacifica* starter types were averaged at each monitoring period and followed over the 16-month term of the study. These results (Fig. 16) indicated that over 80% of the biomass of a *S. pacifica* plant was in the top portion

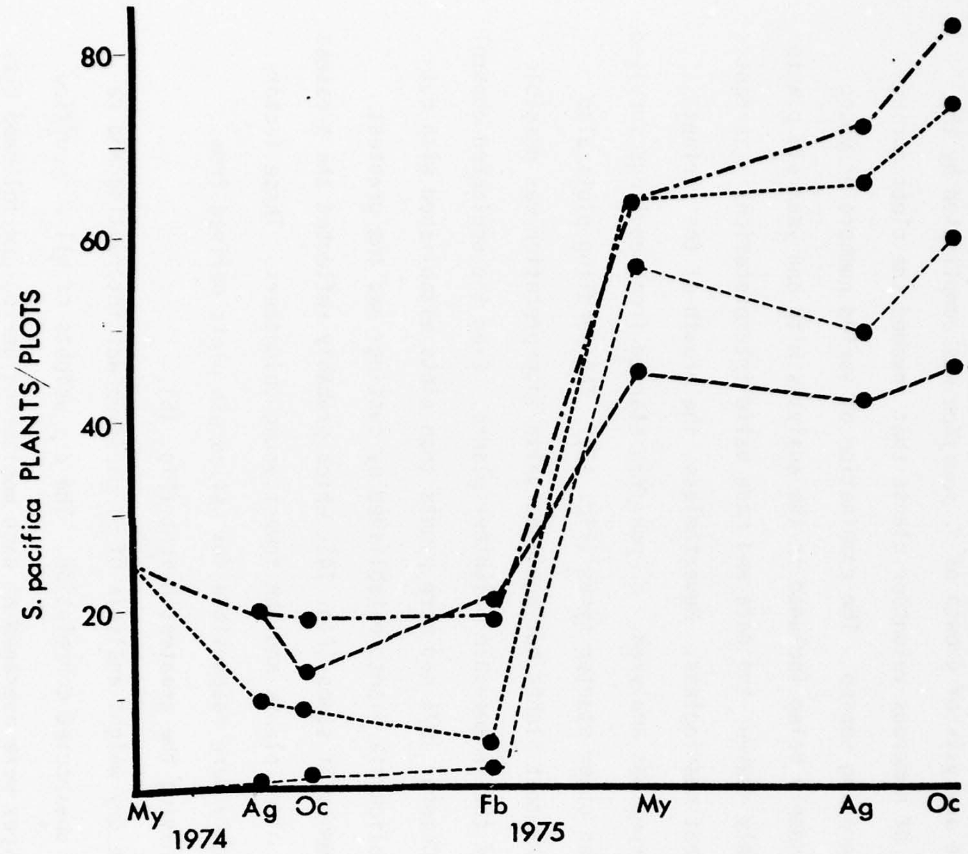

FIGURE 13. Plants per plot of S. pacifica starter type. Symbols: cuttings (— — —), seedlings (·—·—·), shoots (-----), unplanted control (- - - -).

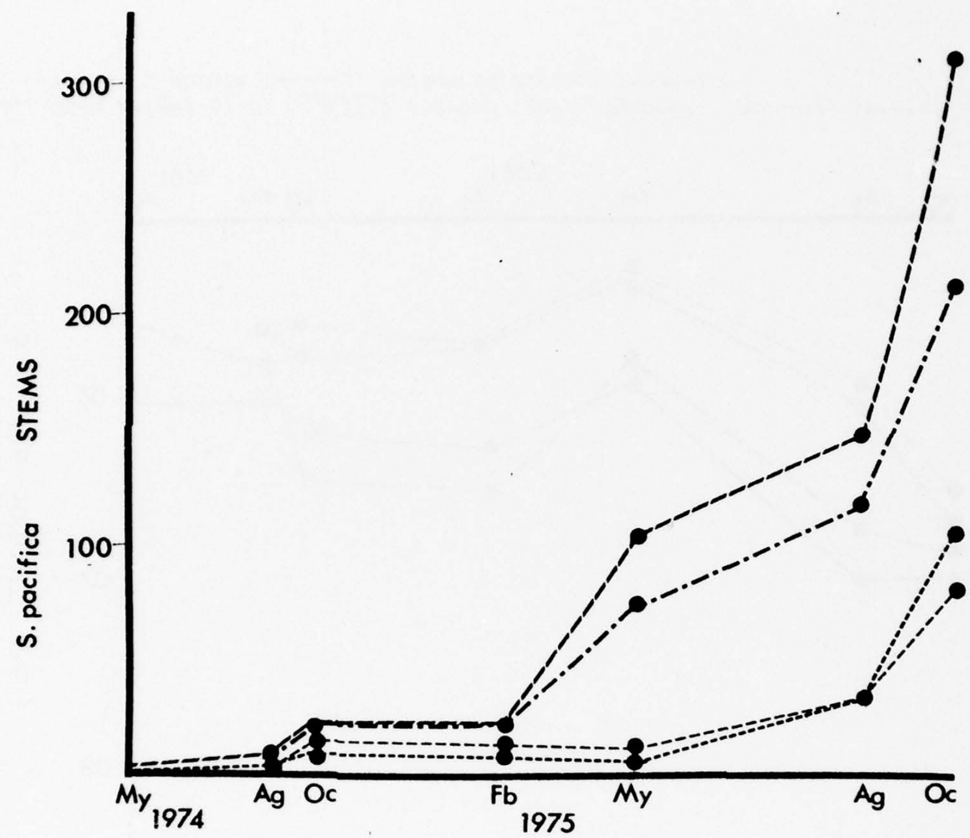

FIGURE 14. Stems per plot of *S. pacifica* starter types. Symbols: cuttings (— — —), seedlings (– · —), shoots (- - - - -), unplanted control (- - - -).

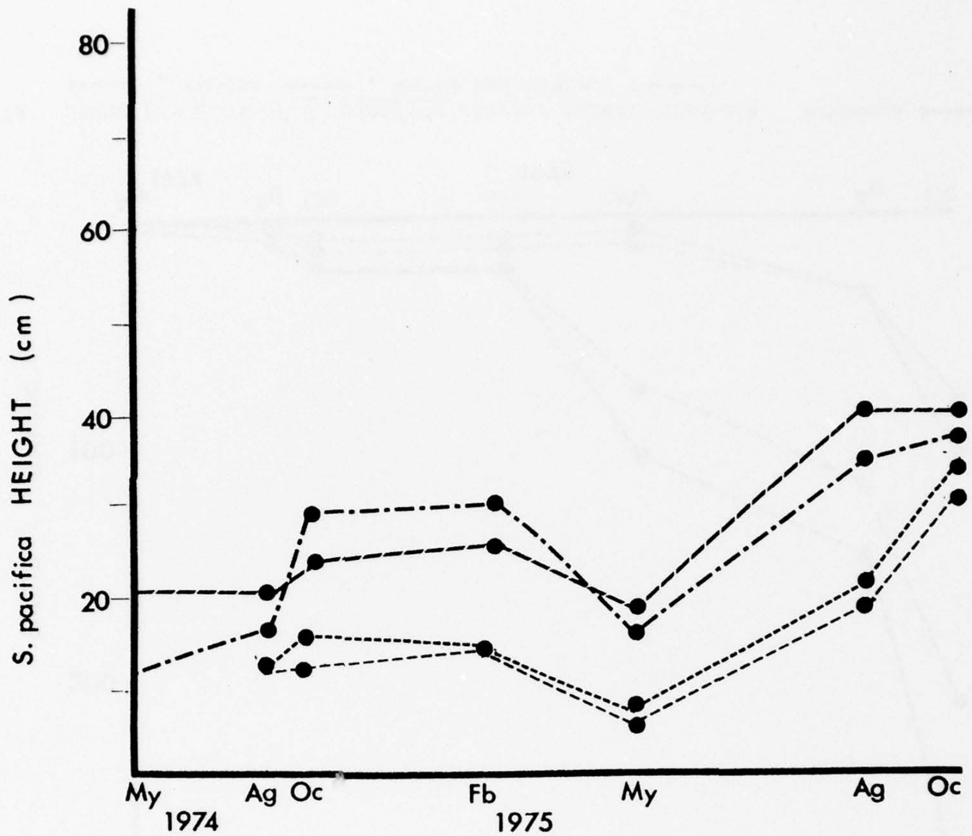

FIGURE 15. *Stem height of* <u>*S. pacifica*</u> *starter type. Symbols: cuttings (▬ ▬), seedlings (• • ▬ •), shoots (- - - - -), unplanted control (- - - -).*

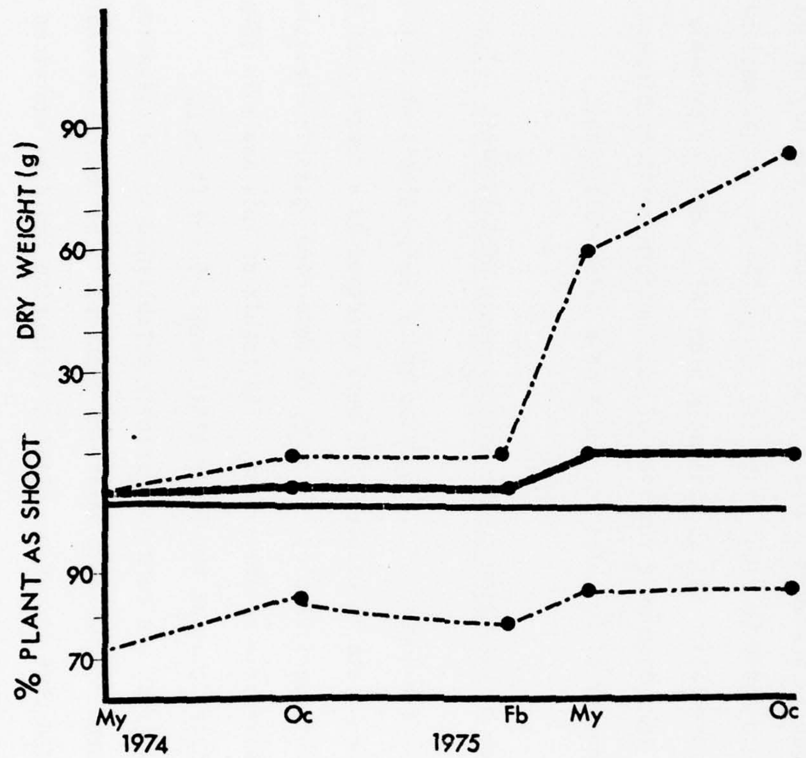

FIGURE 16. Dry weight analysis of S. pacifica growth. Symbols: roots (▬▬), shoots (·—··).

of the plant. The other interesting correlation was that the dry weight of a *S. pacifica* plant could be estimated from the number of stems the plant contained (Fig. 17). Roughly, the number of stems divided by six yielded the dry weight of a *S. pacifica* plant. This dry weight figure divided again by eight (Fig. 17) yielded the dry weight mass of the root. The correlation was surprisingly high (R^2 = .89) and probably reflected stem formation as a function of some uniform critical biomass, such as the number of "pickles" or nodes on a salicornia plant.

Effect of Elevation on the Establishment of Salicornia Volunteers

The number of *S. pacifica* and *S. rubra* plants which invaded *Spartina foliosa* plots in October 1975 were assessed as a function of the elevation of spartina plots in order to determine possible elevational effects on salicornia establishment. The result of this analysis (Fig. 18) indicated that at the lower tidal level, 6 - 9 ft MLLW, *S. pacifica* was more successfully established as the elevation increased, although considerable variation occurred. The regression analysis indicated that 43% of the plant distribution could be explained by elevational effects alone. Similarly, an elevational effect was exhibited by *S. rubra* (Fig. 19). The R^2 of 26% was skewed by one datum (140 plants) and the fact that fewer *S. rubra* seeds were available to colonize the established spartina plots. It should be noticed that plants of both

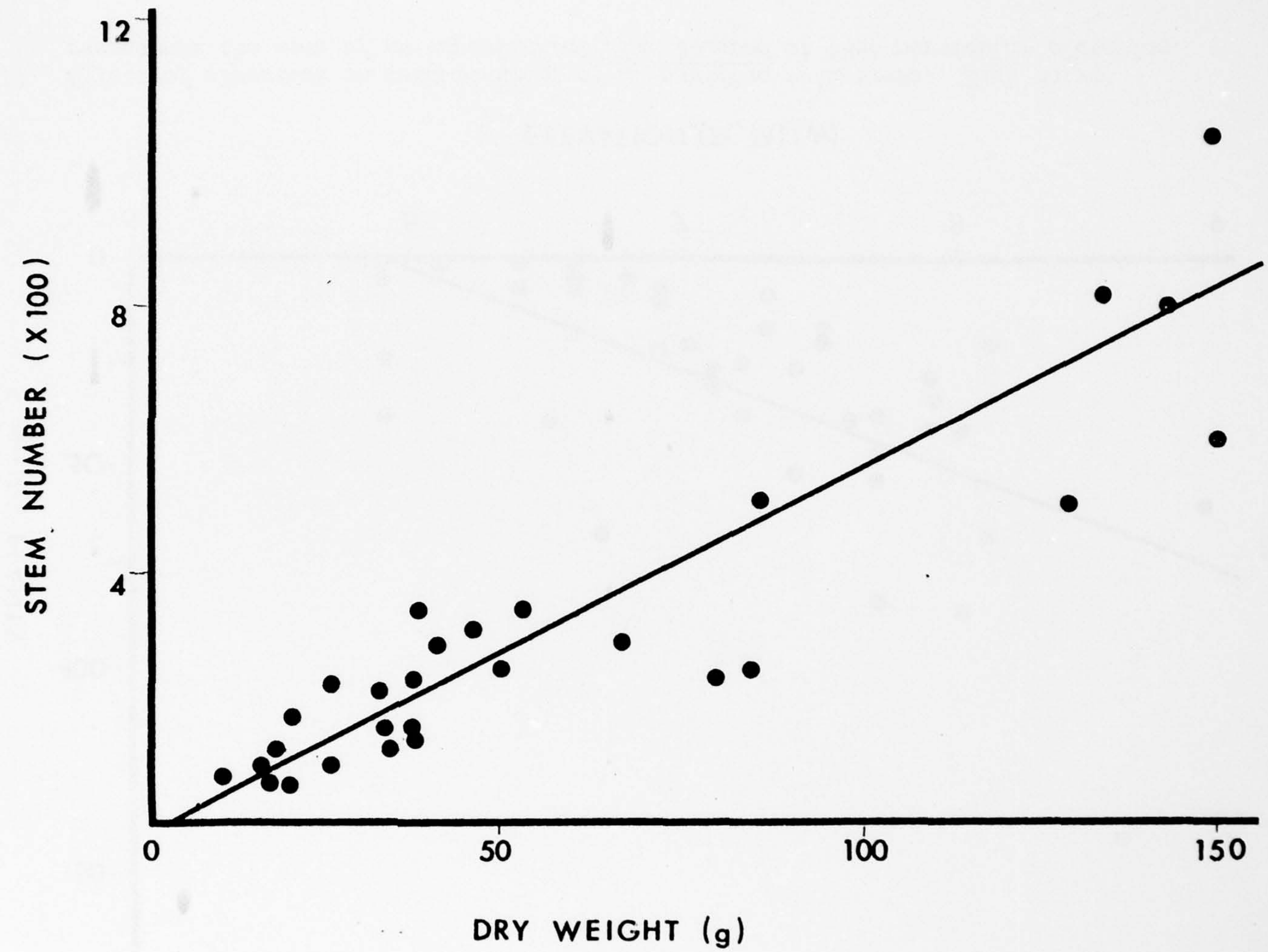

FIGURE 17. Correlation of S. pacifica stem number with dry weight. Each datum represents the analysis of one plot.

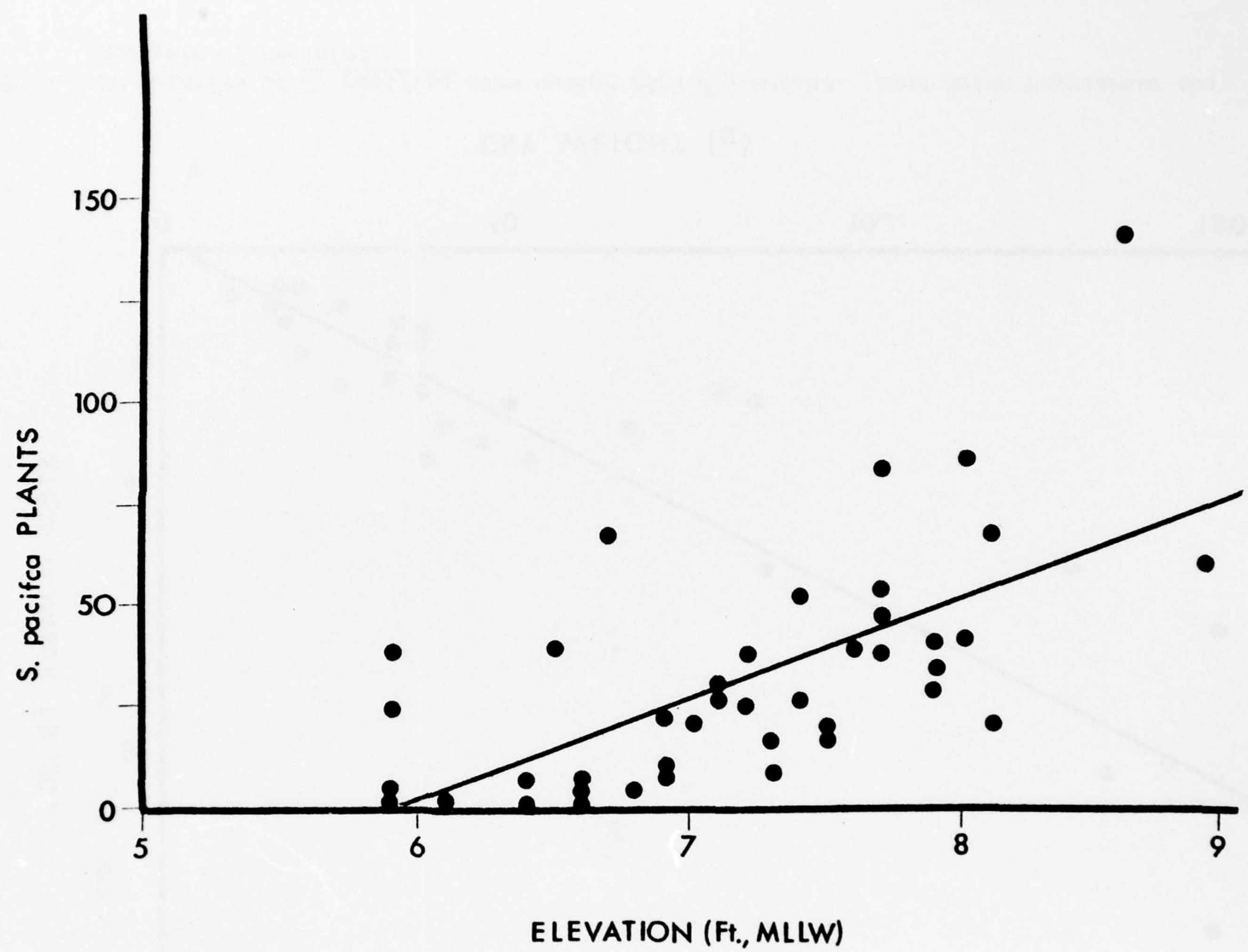

FIGURE 18. *Effect of elevation on establishment of S. pacifica volunteers. Each datum represents the mean of an experimental plot located at that particular elevation.*

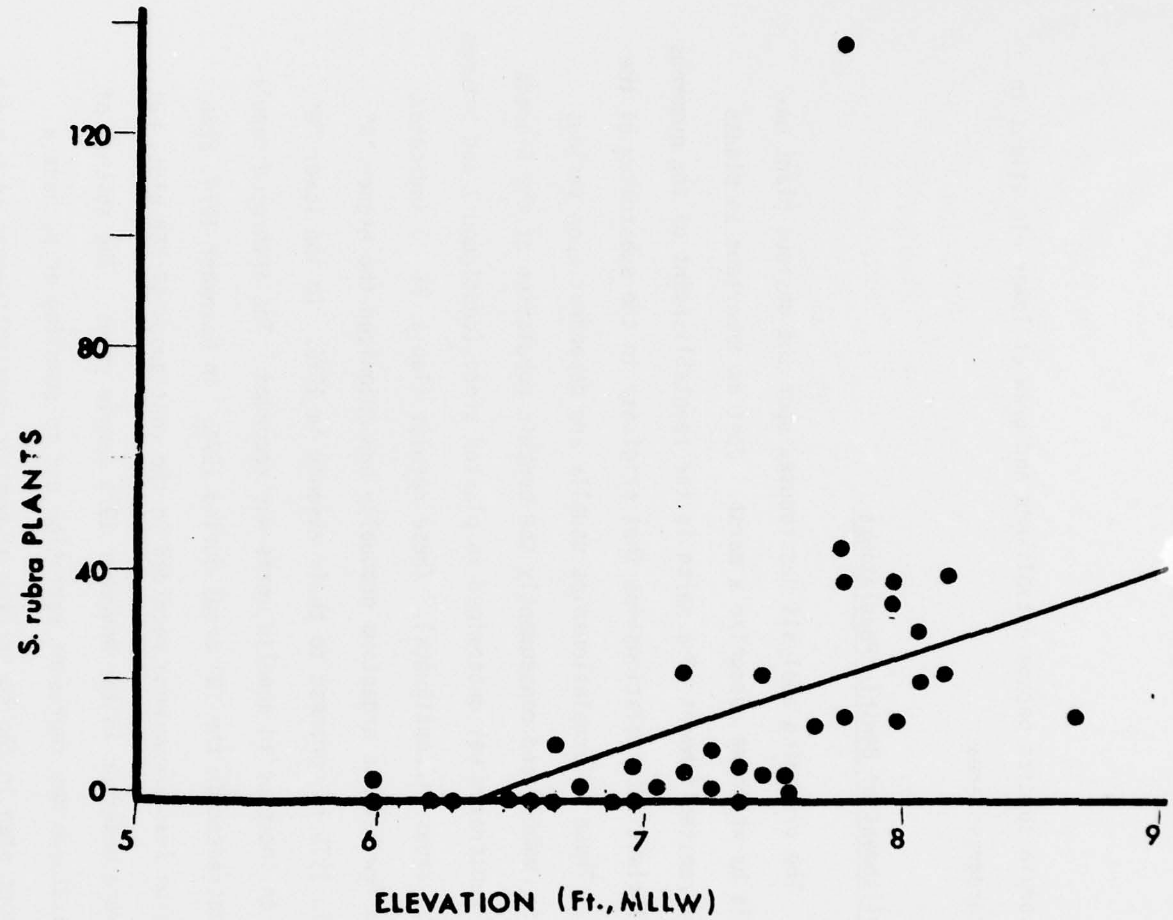

FIGURE 19. Effect of elevation on establishment of S. rubra volunteers. Each datum represents the mean of an experimental plot located at that particular elevation.

salicornia species became established and grew at lower elevations in the cordgrass area.

Establishment of Benthic Populations

The preceding analysis has focused upon the obvious plant materials by which we recognize a marsh. Just as important as plants in the reestablishment of a marsh is the reestablishment of the numerous animal-plant interrelationships that originate in the substratum of the marsh. These interrelationships usually are dependent upon various benthic members and consequently the benthic population of the Alameda Creek substratum was determined in planted areas (contiguous) and between planted areas (incontiguous). These results (Table IX.) indicated that a few benthic organisms gradually had colonized the higher "A" area in 1975 in contrast to their absence in 1974. In the lower "B" area, an increase in annelid worms was recorded. The arthropod population decreased in the "B" areas during 1975. In November 1974, 2266 *Corophium insidiosum* were recorded in the contiguous 47:75B plot, but none were observed in the November 1975 sample grabs. The absence of *C. insidiosum* may represent variation due to sampling or perhaps a transient step in the succession of benthic reestablishment in a marsh. In other plots, large ribbed mussels -- *Ischadium demissum (Modiolus demissus)* -- that originally were attached to spartina plants used as

TABLE IX.

Changes in Benthic Populations of Alameda Creek Substrate

Phyla	1974				1975			
	7' MLLW		9' MLLW		7' MLLW		9' MLLW	
	C	I	C	I	C	I	C	I
Annedlia	468	156	0	0	2287	260	13	260
Arthropod	2697	117	0	0	65	0	13	0
Mollusca	117	78	0	0	26	13	13	13
Insecta	0	0	0	0	286	39	26	39

Populations are expressed as animals/M^2.

C = contiguous plots 47:75A or 47:75B.

I = incontiguous plots 47:50 - 4750A or B.

plugs, continued to grow and many plants contained 6 - 8 specimens approximately 6 - 8 cm in length. A list of the benthic organisms recorded in the experimental plots is presented in Table X.

The appearance of insect larvae in all plots during the 1976 monitoring was encouraging in that members of this Phylum were beginning to utilize the marsh environment. Concomitant with insect utilization of the substratum was the observation of insect larvae in spartina inflorescences and brine flies, spider mites, spiders, and tiger and other beetles on plants in the site area.

One of the most interesting colonizers was the isopod *Sphaeroma pentodon*. On either side of the graded experimental area, this decapod burrowed into the perpendicular bank at 6 - 8 ft MLLW, creating innumerable burrows which facilitated undercutting of the bank by wave action. Populations of 3000/M^2 were estimated burrowed into the ungraded bank. In contrast, the graded experimental area had only a few *S. pentodon* located in small perpendicular meanders created by slumping. It would appear that grading an intertidal area and stabilizing it with plants prevented the occurrence of this decapod and the resultant erosion of dredged material deposited in the 6 - 8 ft MLLW tidal zone.

Changes in Chemical Composition of Growth Substrate

Monitoring the chemical composition of growth substrates is of importance because it often provides reasons for the success or failure

Table X.

Classification of Benthic Invertebrates Recorded in Experimental Plots during 1974 and 1975

Classification	1974	1975
ANNELIDA		
Oligochaeta	None	Present
Polychaeta	*Eteone lighti*	*Eteone dilatae* *Polydora ligni* *Pseudopolydora paucibranchiata*
ARTHROPODA		
Amphipoda	*Corophium insidiosum* *Ericthonius* sp. Other Gammarid amphipods	*Corophium acherusicum* *Orchestia traskiana* *Orchestia chilensis*
Tanadacea (Chelifera)	*Tanais* spp.	
Insecta	None	Adult & Larval
MOLLUSCA		
Bivalvia	*Gemma gemma* *Macoma inquinata (M. irus)*	*Gemma gemma* *Macoma inquinata (M. irus)*
PROTOZOA (Class)	None	Foraminifera

of a plant to grow. The substrates of typical plots located at high and low elevations, and in planted (contiguous) and unplanted (incontiguous) areas were sampled and analyzed for various chemical constituents. These results (Table XI.) indicated that elevation and the presence of (sparse) plants had no effect on the concentration of elements in the substrate. However, the concentration of iron, zinc, lead, and phosphate increased during the year. This could have resulted from leaching from higher elevations or from micro deposits in the dredged material. Nitrogen and organic carbon concentrations were essentially equivalent and apparently were not rate limiting for growth. Whether these trends were applicable to other plots, especially those with excellent plant growth was not known.

Changes in Physical Properties of Growth Substrate

Comparisons of physical properties of the growth substrate (Table XII) indicated the only difference between contiguous and incontiguous areas was an increase in the compression strength of the contiguous areas. This was a reflection of a peculiar distribution of slumped substrate in the incontiguous area rather than any change in soil compression due to plants.

Moisture content was higher in the lower plots, as expected, and was the only physical change which could be attributed to elevation.

TABLE XI.

Changes in Element Concentration of Alameda Creek Substrates

Element	October 1974					October 1975				
	7' MLLW		9' MLLW		mcv	7' MLLW		9' MLLW		mcv
	C	I	C	I		C	I	C	I	
Iron	707.0	663.0	360.0	133.0	23	4462.0	3081.0	1812.0	3104.0	58
Zinc	1.1	1.3	1.3	0.3	17	5.6	4.3	3.0	5.2	33
Lead	1.5	1.5	1.5	1.4	0	13.7	16.7	9.3	11.7	42
Mercury	0.2	0.17	0.06	0.45	29	0.02	0.02	0.02	0.02	0
Calcium	2467.0	2367.0	2300.0	3633.0	16	3261.0	1221.0	3887.0	2033.0	61
Carbon (organic)	6.1	7.6	5.4	8.3	60	6.3	6.3	5.8	5.4	16
Chloride	15.1	15.1	14.2	10.9	20	24.3	21.3	25.3	24.3	10
NO_3N	7.3	6.3	5.7	2.3	19	10.4	4.8	5.3	7.2	28
PO_4	36.3	85.3	67.7	8.0	18	260.0	114.0	260.0	173.0	55

Concentration of all elements in ppm except chloride (ppt) and carbon (%).

Mean coefficient of variation (in %) of all analyses performed at indicated sampling time = mcv.

C = contiguous

I = incontiguous

TABLE XII.

Changes in Physical Properties of Alameda Creek Substrates

Physical Characteristics	October 1974					October 1975				
	7' MLLW		9' MLLW		mcv	7' MLLW		9' MLLW		mcv
	C	I	C	I		C	I	C	I	
Moisture (%)	52.7	53.2	45.8	43.7	4.6	50.5	47.6	44.4	41.8	10.5
Alkalinity (ppm)	108.0	95.0	111.0	100.0	13.0	673.0	723.0	956.0	923.0	41.0
Compression Strength (lb/ft^3)*	214.0	126.0	350.0	442.0		6273.0	237.0	3563.0	438.0	24.0
Particle Size (%):										
< 32 μ	93.9	93.5	92.4	82.8	2.4	67.0	82.0	80.0	75.0	23.0
> 32 < 500 μ	4.5	3.3	4.8	17.1	21.7	32.0	15.0	19.0	22.0	52.0
> 500 μ	1.6	3.1	2.9	0.2	82.0	0.0	2.0	1.0	2.0	71.0

* Unconfirmed.

Mean coefficient of variation (in %) of all analyses performed at indicated sampling time = mcv.

Alkalinity increased and the number of particles in the 32 - 500 μ range increased at the expense of the smaller particles. The most significant change appeared to be the increased uniformity and finer texture of the substrate (increased compression strength) which would facilitate root growth in the dredge material which was softer than the previous year. Another physical property affecting plant growth, mean submergence time, was obtained from the data of Rowntree (1973) for a Palo Alto marsh and estimated to be 8.4 hrs/day at 6 ft MLLW and 5.5 hrs/day at 7 ft MLLW for the Alameda site.

Visual Impression of Experimental Site

Impressions which are not adequately documented by photographs or represented by data are noteworthy because they bring an additional element of realism and experience into the interpretation of results. Such was the case for the Alameda Creek marsh study. The overall impression was that the higher "A" plots contained as much *S. pacifica* as did the remainder of the Alameda Creek berm at comparable elevations. The denuded area above the "A" area did not contain appreciable vegetation but neither did comparable adjacent areas. The lower "B" and "C" areas

contained notable slumping but no evidence that growth of spartina was affected by soil movement since some areas with either poor or excellent growth had comparable slumping. In several "C" plots, spartina was migrating, even towards the channel at an estimated elevation of 5.5 ft MLLW. In many plots, spartina culms were broken and in several cases it could be ascertained that they had been chewed by small animals. Rabbit droppings were prevalent in the plots and possibly rabbits were the culprits. On one occasion, coots were seen grazing on small shoots of spartina. The result of the indiscriminant grazing was that data didn't always reflect the best growth. This was particularly true of several plots populated with spartina derived from plugs which had many plants over 70 cm in height. Another noticeable effect was that the surface of some "B" and "C" plots would support a person while in most plots one would sink 4 - 6 inches in mud of pudding consistence. This indicated soil differences between plots which could affect the growth rate of plants. Digging in the plots often uncovered iron and wood artifacts that could affect chemical determinations. The soil by the roots of over 20 plants examined was sulfide black. No visible evidence of soil oxygenation by spartina roots was evident, although the top 1 - 2 cm of soil was lightly colored. *Salicornia rubra* and *S. pacifica* were the only plants to invade the planting site. These salicornia were found equivalently distributed in areas adjacent to the experimental site. Sparse and sporadic patches of *Distichlis spicata, Frankenia grandiflora* and *Mesembryanthyum* sp. were the only other plants observed along the Alameda channel berm. Finally,

unplanted areas adjacent to the experimental "B" and "C" plots as well as several control plots were unpopulated by spartina. The best plots (plugs) had only 1/4 to 1/3 of the surface covered with spartina, although many rhizomes were sending shoots into the unpopulated areas. The planting site definitely was not as populated as spartina stands upcreek.

DISCUSSION

The reason for monitoring animal and plant repopulation rates, as well as changes in soil content and structure of this experimental marsh, was to develop techniques and knowledge for future marsh creation on dredged material in San Francisco Bay. The results, after 18 months of study, indicated that *S. foliosa* and *S. pacifica* survived and grew on dredged material and that benthic forms had begun to populate the intertidal plots. By two criteria -- lack of diversity of the animal and plant population, and comparison of plant density with an older, upcreek marsh -- the experimental marsh area was still developing. Nevertheless, this study indicated that marsh creation on dredged material was feasible, and indicated techniques and information valuable for future planting on dredge material.

The factors which influenced growth and survival of spartina were only partially apparent. Large starter types with balanced root growth survived and initially grew best. Yet equations of growth (Table VII) indicated that diverse starter types would produce mature spartina stands at approximately the same time. This possibly may result from compression changes in the substrate in that the hard, lumpy substrate was smoothed and loosened by constant tidal and microbial action. The substrate change would alter percolation rates of nitrate and other nutrients, resulting in root growth

that was a prerequisite to shoot growth (Fig. 6 - Fig. 7). Smaller plants with roots closer to the surface would be less affected initially by the compact soil than larger plants, although their rate of rhizome (and shoot) growth would not be as spectacular as with the larger plants.

Another factor influencing survival of plants was flotsam. Upcreek, sections of a mature stand of spartina were denuded through constant grinding by flotsam. It is conceivable that sloped areas accessable to flotsam might experience obliteration of large numbers of plants in an area by a large floating object. This notion would explain the localized absence of plants in several plots as well as the plethora of driftwood above the "A" plots. Alternatively, microgeological areas may exist in the dredged substrate that may be detrimental to plant growth.

The survival and growth of *S. foliosa* on the Alameda Creek site compared favorably with results obtained with *S. alterniflora* on dredged material on Atlantic coast sites. Woodhouse *et al.* (1974) found both seeding and transplanting methods successful on sandy dredged material in North Carolina. Extensive seeding produced more plant cover than transplanting methods at the end of the first growing season, although both methods yielded equivalent spartina stands at the end of the second growing season. Dunstan *et al.* (1975) successfully transplanted *S. alterniflora* on a silt-clay dredge spoil substrate in Georgia. Dunstan *et al.* (1975) found an elevational effect on growth and survival of *S. alterniflora*. No

elevational effects were found in this study with the different starter types, although the Alameda Creek site was not planted as extensively at higher elevations as was the Georgia site. The elevational effect may be a consequence of species difference. Dwarf *S. foliosa* was present at higher elevations along Alameda Creek, although its growth was severely retarded (Table VI). The diminished growth was probably a consequence of diminished nutrition rather than any inherent genetic change, since "dwarf" seedlings grew as well as "robust" plugs in this study. A similar conclusion was reached by H.T. Harvey (personal communication) that the phenotypic difference was caused by environment and not by heredity changes.

The ability of *S. foliosa* to produce viable seed and repopulate by seed is worthy of comment. A notion has developed (Rowntree, 1973; Mason, 1973) that *S. foliosa* does not produce viable seed except under certain circumstances and repopulates only by rhizome migration. This is in part true. However, inspection of numerous stands of *S. foliosa* in and outside San Francisco Bay has revealed that every stand produces viable seed. Usually only the first seed on a spikelet of an inflorescence contains an embryo. This results in over 95% of the seed being non-viable. Further inspection of San Francisco Bay reveals innumerable small stands of *S. foliosa* that could have originated only from seed. From the practical standpoint of producing *S. foliosa* stands quickly and economically, it seems reasonable that seeds should be used. The problem of collecting viable seed and insuring that this seed develops into plants

does not seem insurmountable. Garbisch (personal communication)* has developed a flotation technique for enrichment of viable seeds and various concerns currently market paper-containing devices for maintaining seeds in place. The use of some device to maintain seeds in place should improve upon the 1% establishment of *S. foliosa* from seed obtained in this study.

One of the more interesting features of this study was the growth behavior of *S. foliosa* roots. A hypothesis could be generated that growth of shoots was dependent upon the accumulation of some energy storage compound in the roots. This hypothesis would explain the initial emphasis on root growth in the first year development of a plant and would explain the decrease in root biomass in the spring when the rate of shoot growth was maximal. The root energy storage concept might explain the essential linear relationship of plant height to overall biomass observed for larger plants. The concept would explain the overwhelming molasses aroma that one obtains from drying roots (and shoots). Even the better survival rate of large plugs could be attributed to increased quantities of a storage material. This hypothesis is worthy of further testing.

The results of this study could be used to describe a continuous growth cycle of *S. foliosa* for the temperate San Francisco Bay area. As soon as inflorescence developed and matured, new shoots arose around the base of the plant and rhizomes elongated sending up new shoots. The latter growth occurred during the late fall and early winter as large

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*Dr. Edgar W. Garbisch, the head of Environmental Concern, St. Michaels, MD.

senescent culms were lost from the plant. In the spring, the shoots developed into culms which grew and developed florescence by late summer or early fall. The continuous growth of *S. foliosa* along Alameda Creek undoubtedly accelerated the repopulation of the experimental site. Whether continuous growth of *S. foliosa* is a genetic characteristic or a permissible characteristic in the mild, temperate climate of San Francisco Bay is not known but worthy of further testing since the use of this plant would accelerate repopulation of denuded intertidal substrates.

ACKNOWLEDGMENTS

Thanks are expressed to all persons who have contributed to this study: To Dr. Jerrold Jayne for supervising the chemistry work; to Dr. H. Thomas Harvey for valuable consultation in marsh ecology; to Mr. James Morris, Ms. Carol Purser, and Ms. Roslyn Mueller for laboratory assistance; and to Messrs Michael Castelli, Charles R. Pride, and John Malmsley for assisting in field aspects of the investigation.

Special acknowledgment is made to Dr. Carl Peck for helpful counsel in all aspects of the statistical work.

Mr. Paul Knutson, Biologist of the Army Corps of Engineers, San Francisco District Office, monitored the project and provided helpful information and administrative guidance in all phases of the investigation.

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MEMORANDUM

November 14, 1975

To: Dr. C. Newcombe, Director
S.F. Bay M.R.C. Inc.
8 Middle Road
Lafayette, Ca. 95192

From: Dr. H. T. Harvey

Re: *Spartina foliosa* survival and growth along elevational transects.

The November 20, 1974 memorandum gives most of the basic data regarding numbers of transplants, tidal elevation ranges and survival of plantings as of October 1974. This report updates the previous report with data gathered during August and October 1975. In October 1974 survival of all plugs was about 64%-as of October 1975 it had dropped to 48%. By suspected ecotype, the survival of the robust form had dropped from 50% to 37% during the year while the dwarf form had dropped from 78% to 57% survival. Thus each seemed to have succumbed to adverse forces at about the same rate. The probable factors that favored dwarf form survival still appear to be short stature and more culms per plug at time of transplanting.

The highest elevations at which there are still survivors is at +8.68 ft. above MLLW. It is a dwarf form plant in transect 41 _ 25. Contrary to the hypothesis suggested in the 1974 report the plantings at the lower elevations did exceed the tolerance levels of the plants. Although elevations have not been run on the lowest survivors it is interesting to note that the dwarf form is surviving at a lower elevation than its paired robust plug in three paired transects, equal in one, and higher in three transects. These data strongly support the hypothesis that the two suspected forms are not ecotypes but simply the response of the species to extremes of the physical elevational gradients of factors. The highest survivors are dwarf forms in five paired transects and both dwarf and robust in two paired transects. On the surface this appears to support the hypothesis of two ecotypes, however, the higher survival rate of "dwarf form" may actually be the determining factor. The number of shoots per plug was significantly greater for the dwarf form at about 32 shoots per plug while the robust form averaged only about 19 shoots per plug. The heights of culms (or shoots) provided a perplexing set of data. The following chart summarizes that data.

	Robust		Dwarf	
	August	October	August	October
Small Plugs	26.3cm*	18.7	22.7	12.7
Large Plugs	26.9	18.0	22.9	16.8
Large + Small	26.6	18.3	22.7	13.9

The dwarf form appears to be shorter on the average than the robust form. However, the greater survival of dwarfs at the higher elevations distorts the averages. When a sample of middle elevation pairs of robust versus dwarf are compared as to average height no significant difference was noted. When height measurements are pooled for August and October 1975, 687 robust shoots averaged 22.8cm in height while 1,144 dwarf shoots mean height was 23.4cm. These data support the hypothesis that there are not two ecotypes.

There were 4.5 times as many fruiting culms in dwarf transects as in robust transects (282 vs. 63) in October 1975.

Conclusions and Summary

The survival of cordgrass plug transplants depends on size of plug, physiological form of transplant and elevation at which they are planted. "Dwarf" plugs suvived better than "robust" plugs. Large plugs (6" dia.) survived better than small plugs. Although elevations should be rerun it appears that plugs between +5' and +8' above MLLW survived best.

None of the data clearly indicate that the two suspected ecotypes do in fact exist but rather the short form is a physiological response to the harsh environment at the upper elevational range of the species.

DATA SHEET

Transect Number	Robust August * Sh.	Robust August Ht.	Robust October Sh.	Robust October Ht.	Dwarf August Sh.	Dwarf August Ht.	Dwarf October Sh.	Dwarf October Ht.	
41 + 25	16	112	15	72	107	696	105	879	Small plugs
41 + 75	60	522	95	598	272	2101	402	2528	Small plugs
44 + 25	157	1783	203	1447	538	5254	615	5104	Small plugs
44 + 75	58	575	70	517	357	3425	514	3848	Small plugs
47 + 75	109	1255	160	1361	161	1272	283	1480	Small plugs
44 + 50	250	2965	302	2218	449	4279	591	4127	Large Plugs
47 + 25	195	1752	204	1373	287	2379	284	1659	Large Plugs

Small	400	4135	543	4001	1435	12,748	1919	9,614
Large	445	4717	506	3591	736	6,658	875	5,786
Large+ Small	848	8852	1049	7592	2171	19,406	2794	15,400
Small	80	827	108	800	287	2,549	382	1,832
Large+ Small	120	1264	149	1085	310	2,722	399	2,200

* Sh.= Shoots
Ht.= Height in inches

INCLOSURE FOUR

SAN FRANCISCO BAY AND ESTUARY DREDGE DISPOSAL STUDY

MARSH DEVELOPMENT STUDY

SEDIMENT ANALYSIS DATA

1. Alameda Creek Flood Control Channel sediments before dredging (April 1972)

2. Alameda Creek Flood Control Channel sediments after disposal in marsh development area (November 1975)

REPORT OF TESTS
FOR
POLLUTANTS IN BOTTOM SEDIMENT SAMPLES

ALAMEDA CREEK FLOOD CONTROL PROJECT

April 1972

AUTHORIZATION

1. Results of tests reported herein were requested by DA Form 2544, No. E86-72-3038, 21 March 1972, from the San Francisco District.

PURPOSE

2. The purpose of this study was to determine the quantities of specified pollutants in bottom sediment samples.

SAMPLES

3. Ten composite samples, in glass jars, were received on 15 and 16 March 1972. Sample identification is included in Table 1.

TESTS

4. Tests were performed as follows:

a. Volatile solids, chemical oxygen demand (COD), total Kjeldahl nitrogen, oil and grease, lead and zinc were run according to "Chemistry Laboratory Manual, Bottom Sediments", compiled by Great Lakes Region Committee on Analytical Methods and published by the Environmental Protection Agency (EPA), Federal Water Quality Administration, December 1969.

b. Mercury, Hatch and Ott Method using Coleman 50 Mercury analyzer.

c. Particle size, Engineer Manual EM 1110-2-1906.

TEST RESULTS

5. Test results are presented as follows:

a. Table 1 identifies the samples.

b. Table 2 shows chemical analyses of the samples. The ingredients are shown as percent of dry weight of the samples or as $1x10^{-4}$ percent (or parts per million) of dry weight.

1 part per million (ppm) = $1x10^{-4}$ percent
(1 ppm = 0.0001 percent)
1 percent = 10,000 ppm

c. ENG Forms 2087 show gradation curves for the samples.

COMMENTS

6. The following comments are made:

a. All samples exceeded the EPA limit for zinc. All but two samples exceeded the EPA limit for volatile solids. All but two samples exceeded the limit for Kjeldahl nitrogen. Four samples exceeded the limit for chemical oxygen demand.

b. The samples contained numerous small roots which added to the volatile solids, COD and Kjeldahl nitrogen.

TABLE 1

ALAMEDA CREEK FLOOD CONTROL PROJECT

IDENTIFICATION
OF
BOTTOM SEDIMENT SAMPLES

Laboratory No.	Hole No.	Location			
PC-350	2D-1	Station	16+00,	50 ft.	left of CL
PC-351	2D-2	"	25+00,	100 ft.	left of CL
PC-352	2D-3	"	66+00,	100 ft.	left of CL
PC-353	2D-4	"	80+00,	50 ft.	right of CL
PC-354	2D-5	"	72+00,	50 ft.	right of CL
PC-355	2D-6	"	118+50,		CL
PC-356	2D-7	"	110+50,	25 ft.	right of CL
PC-357	2D-8	"	100+00,		CL
PC-358	2D-9	"	55+00,	100 ft.	left of CL
PC-359	2D-10	"	31+00,	100 ft.	left of CL

NOTE: CL = Center line

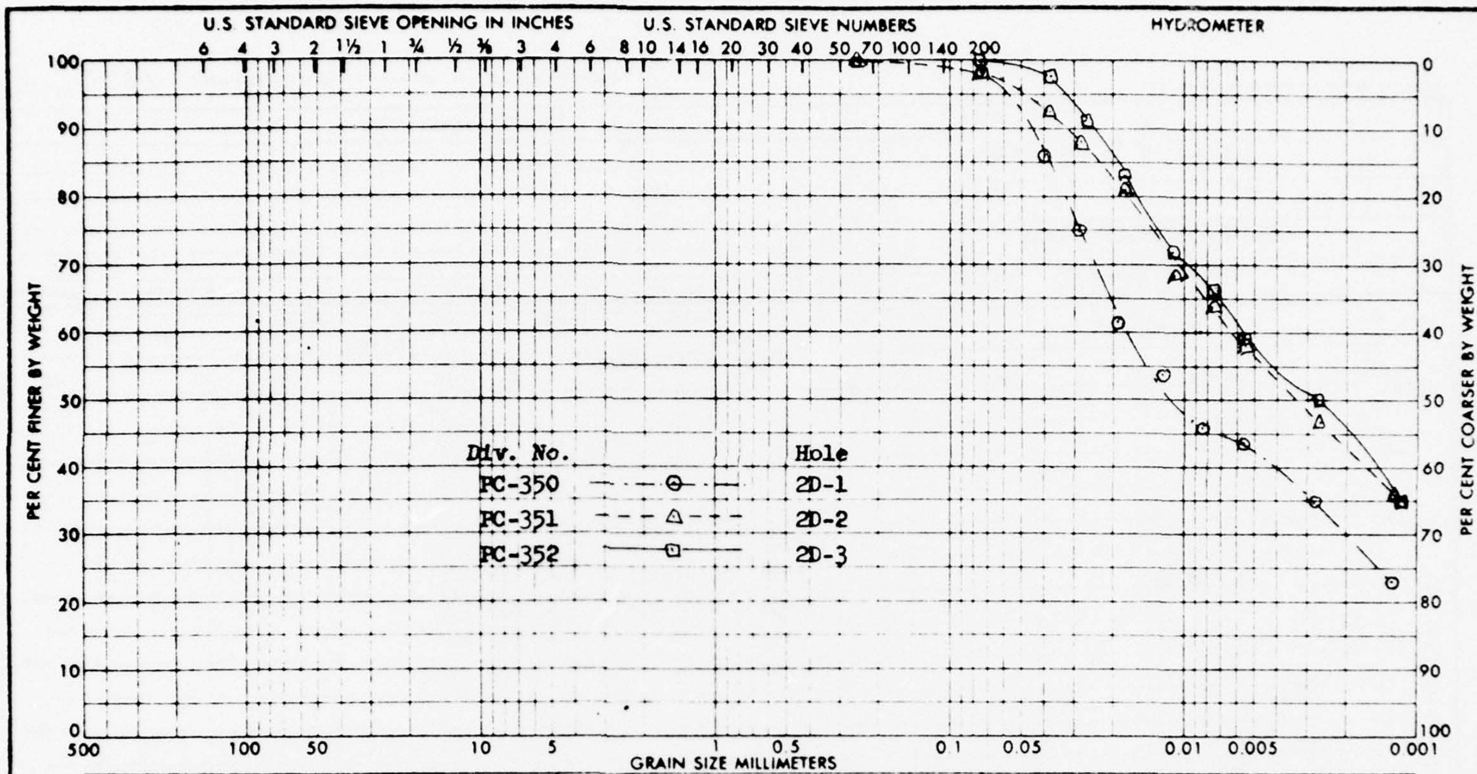
TABLE 2

ALAMEDA CREEK FLOOD CONTROL PROJECT

CHEMICAL ANALYSIS
OF
BOTTOM SEDIMENTS

Laboratory No.	Hole No.	Moisture Content, % dry wt.	Volatile Solids, % dry wt.	C.O.D., % dry wt.	Total Kjeldahl Nitrogen, % dry wt.	Oil & Grease, % dry wt.	Reported as $1X10^{-4}$ percent of dry wt. Mercury Hg	Lead Pb	Zinc Zn
PC-350	2D-1	102.9	6.6*	5.9*	0.13*	0.10	0.68	8	95*
PC-351	2D-2	102.9	7.8*	5.0	0.13*	0.10	0.78	13	101*
PC-352	2D-3	95.9	7.3*	4.7	0.13*	0.13	0.39	13	118*
PC-353	2D-4	84.0	7.3*	5.0	0.13*	0.08	0.49	10	99*
PC-354	2D-5	99.7	7.4*	5.3*	0.12*	0.11	0.47	8	116*
PC-355	2D-6	63.1	4.3	2.3	0.07	0.02	0.25	10	109*
PC-356	2D-7	98.7	7.9*	7.0*	0.15*	0.10	0.33	7	93*
PC-357	2D-8	70.8	4.8	3.3	0.08	0.05	0.32	8	139*
PC-358	2D-9	112.7	7.8*	6.3*	0.15*	0.10	0.50	10	115*
PC-359	2D-10	103.1	6.4*	5.0	0.10	0.09	0.53	10	112*
E.P.A. Maximum Limits		-	6.0	5.0	0.10	0.15	1.0	50	50

*Exceeds EPA limits.



COBBLES	GRAVEL		SAND			SILT OR CLAY
	COARSE	FINE	COARSE	MEDIUM	FINE	

SAMPLE NO	ELEV OR DEPTH	CLASSIFICATION	NAT W%	LL	PL	PI

PROJECT ALAMEDA CREEK
FLOOD CONTROL PROJECT

AREA

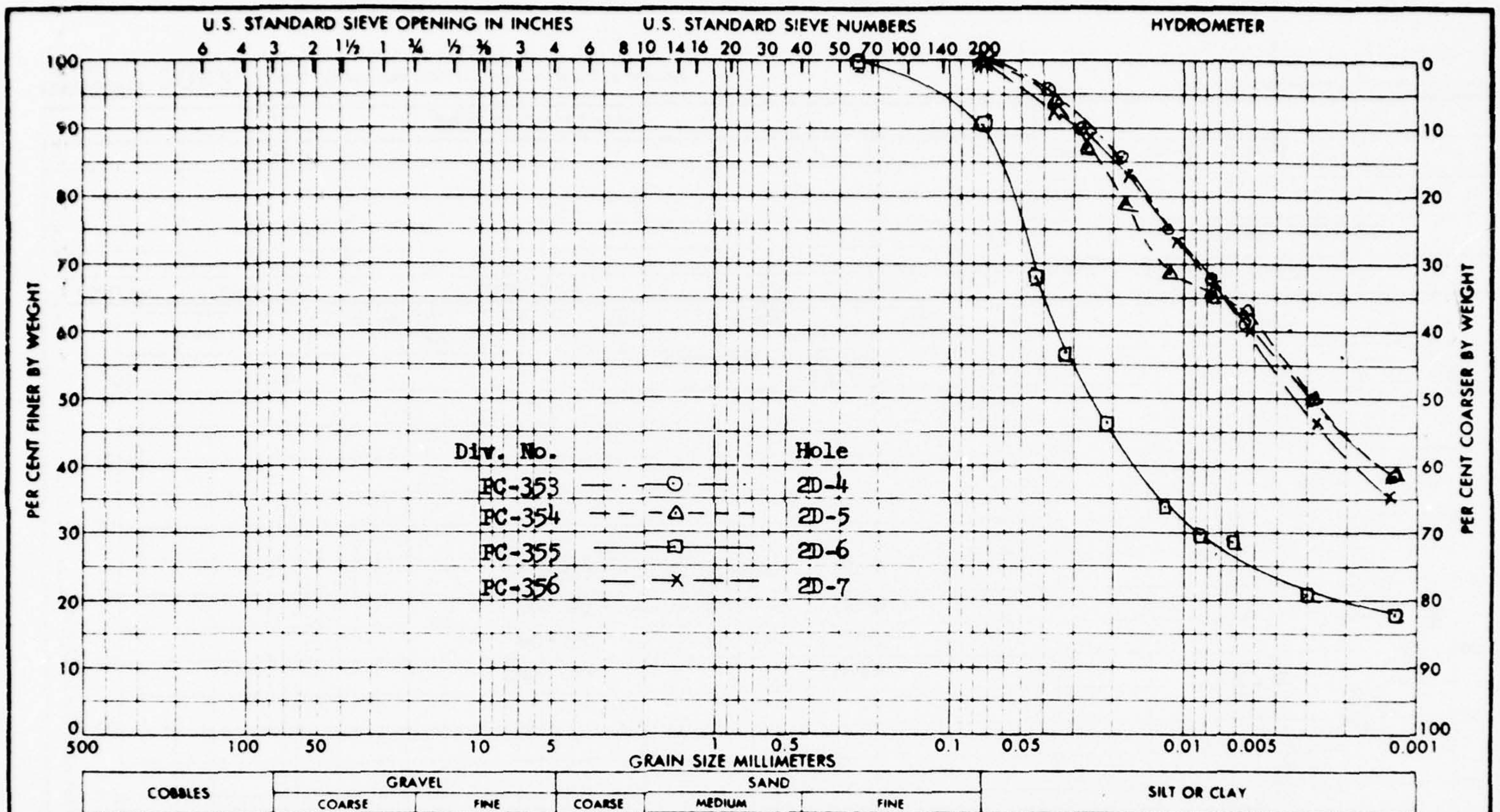
BORING NO 2D-1, 2 & 3

DATE

GRADATION CURVES

ENG FORM 2087
1 MAY 63

REPLACES WES FORM NO 1241, SEP 1962, WHICH IS OBSOLETE



SAMPLE NO	ELEV OR DEPTH	CLASSIFICATION	NAT W%	LL	PL	PI

GRADATION CURVES

PROJECT ALAMEDA CREEK
FLOOD CONTROL PROJECT

AREA

BORING NO 2D-4, 5, 6, & 7

DATE

ENG FORM 2087
1 MAY 63

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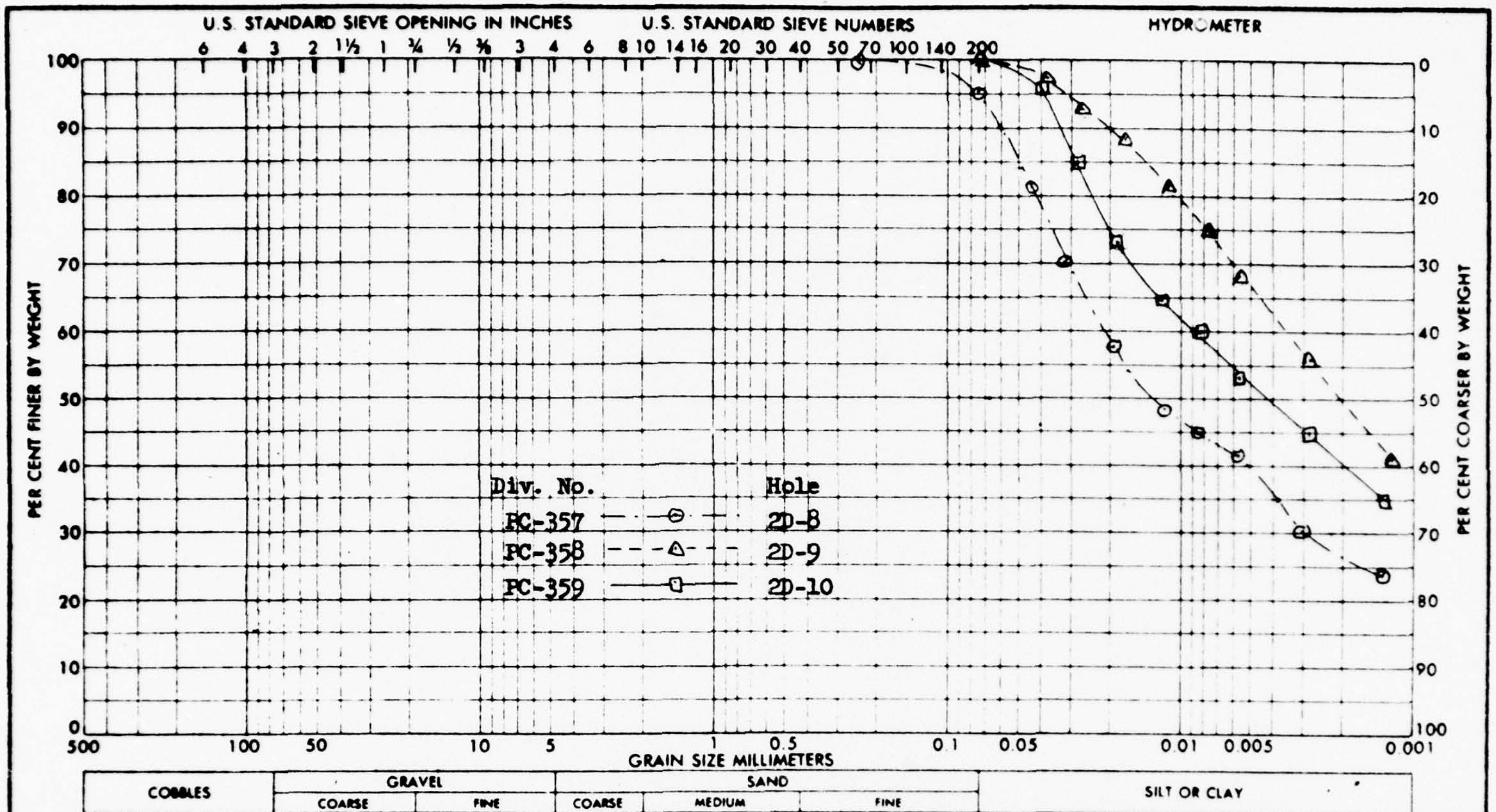


SAMPLE NO	ELEV OR DEPTH	CLASSIFICATION	NAT W%	LL	PL	PI

GRADATION CURVES

PROJECT ALAMEDA CREEK
FLOOD CONTROL PROJECT

AREA

BORING NO 2D-8, 9, & 10

DATE

ENG FORM 2087
1 MAY 63

REPLACES WES FORM NO 1241, SEP 1962, WHICH IS OBSOLETE

ALAMEDA CREEK
MARSH DEVELOPMENT DISPOSAL AREA
SEDIMENT ANALYSIS

November 1975

AUTHORIZATION

1. Results of tests reported herein were requested by DA Form 2544, No. E86-76-3004, 11 August 1975, and Change Order No. 1, 10 September 1975 from the San Francisco District.

PURPOSE AND SCOPE

2. The purpose of this study was to determine the quantities of specified constituents, grain-size distribution, and Atterberg Limits on samples of sediments.

SAMPLES

3. Ten undisturbed, three-inch tube samples were received on 12 August 1975.

TEST METHODS

4. Tests were performed as follows:

a. Moisture, volitile solids, copper, cadmium, lead, iron, zinc, mercury, and nickel were run according to "Preliminary sampling and Analytical Procedures for Evaluating the Disposal of Dredged Materials", Laboratory Support Branch, Environmental Protection Agency, Region IX, April 1974.

b. Conductivity was run by "Standard Methods for Examination of Water and Wastewater", published by American Public Health Association, etc., 13th Edition 1971, referred to as Standard Methods, on a sample prepared by suspending 10 grams of sediment in 100 grams of distilled water.

c. Salinity, chemical oxygen demand, biological oxygen demand, total kjeldahl nitrogen, phosphate, carbonate, bicarbonate, sulfate, chloride, sulfide, calcium, magnesium, and sodium- potassium were run by standard methods on a sample prepared by suspending 100 grams of sediment in 1000 grams of distilled water and then filtering the resultant suspension.

d. Testing methods for the grain-size distribution and Atterberg Limits conformed to the procedure described in Engineer Manual, EM-1110-2-1906, "Laboratory Soil Testing", 30 November 1970.

TEST RESULTS

5. Test results are reported as follows:

a. Tables 1 through 10 show results of chemical tests. The ingredients are shown as percent, parts per thousand, or parts per million of dry weight.

1 Part per thousand (PPT) = 1000 parts per million (PPM)
1 Percent = 10,000 PPM
1 PPT = 0.1 Percent
1 PPM = 0.0001 Percent

b. Plates 1 through 10 show the results of the grain-size distribution tests.

c. Plate 11 shows the results of the Atterberg Limits tests.

TABLE 1
Alameda Creek
Sediment Analysis
Hole No. SP-1

Depth, Ft.	0 - 0.9	0.9-1.9	1.9-2.8
Laboratory No.	PC-2388	PC-2389	PC-2390
pH	7.2	6.8	5.7
Moisture, % of Dry Weight	64.4	76.3	83.0
Volitile Solids, % of Dry Wt	9.2	8.8	9.4
Conductivity, micromhos (a)	6730	6250	7050
Salinity, PPT of Dry Wt	101.0	79.6	100.0
Chemical Oxygen Demand, PPT of Dry Wt	45.1	56.1	56.5
Biological Oxygen Demand, PPM of Dry Wt	658	952	805
Total Kjeldahl Nitrogen (N), PPM of Dry Wt	1470	2010	2020
Phosphate (P), PPM of Dry Wt	0.3	0.2	0.3
Carbonate (CO_3), PPM of Dry Wt	45	50	55
Bicarbonate (HCO_3), PPM of Dry Wt	443	613	351
Sulfate (SO_4), PPM of Dry Wt	9100	8740	19200
Chloride (Cl), PPT of Dry Wt	45.1	34.0	35.0
Sulfide (S), PPM of Dry Wt	373	417	4-
Calcium (Ca), PPM of Dry Wt	850	883	3680
Magnesium (Mg), PPM of Dry Wt	3220	2270	3010
Sodium-Potassium (Na), PPM of Dry Wt	2658	2205	2211
Copper (Cu), PPM of Dry Wt	39	39	32
Cadmium (Cd), PPM of Dry Wt	0.2	0.3	0.2
Lead (Pb), PPM of Dry Wt	23	23	16
Iron (Fe), PPT of Dry Wt	42.6	46.0	40.2
Zinc (Zn), PPM of Dry Wt	92	104	81
Mercury (Hg), PPM of Dry Wt	0.9	0.5	0.5
Nickel (Ni), PPM of Dry Wt	95	104	88

(a) Conductivity of Suspension of 10g of sediment in 100g of water

TABLE 2
Alameda Creek
Sediment Analysis
Hole No. SP-2

Depth, Ft.	0 - 0.9	0.9-1.9	1.9-2.8
Laboratory No.	PC-2391	PC-2392	PC-2393
pH	7.2	7.1	7.7
Moisture, % of Dry Wt	52.3	78.0	88.8
Volitile Solids, % of Dry Wt	3.3	7.8	8.7
Conductivity, micromhos (a)	5460	3630	4220
Salinity, PPT of Dry Wt	69.2	43.2	49.1
Chemical Oxygen Demand, PPT of Dry Wt	38.4	46.8	65.9
Biological Oxygen Demand, PPM of Dry Wt	1036	888	1133
Total Kjeldahl Nitrogen (N), PPM of Dry Wt	1210	1560	2300
Phosphate (P), PPM of Dry Wt	0.2	0.5	0.4
Carbonate (CO_3), PPM of Dry Wt	50	38	39
Bicarbonate (HCO_3), PPM of Dry Wt	659	877	1165
Sulfate (SO_4), PPM of Dry Wt	2600	4090	5340
Chloride (Cl), PPT of Dry Wt	32.0	19.0	21.0
Sulfide (S), PPM of Dry Wt	35	161	1660
Calcium (Ca), PPM of Dry Wt	699	332	398
Magnesium (Mg), PPM of Dry Wt	2070	790	1040
Sodium-Potassium (Na), PPM of Dry Wt	1908	1279	1471
Copper (Cu), PPM of Dry Wt	33	41	41
Cadium (Cd), PPM of Dry Wt	0.1	0.1	0.3
Lead (Pb), PPM of Dry Wt	18	22	26
Iron (Fe), PPT of Dry Wt	42.6	48.1	49.1
Zinc (Zn), PPM of Dry Wt	79	98	104
Mercury (Hg), PPM of Dry Wt	0.4	0.5	0.5
Nickel (Ni), PPM of Dry Wt	110	101	108

(a) Conductivity of Suspension of 10g of sediment in 100g of water

TABLE 3
Alameda Creek
Sediment Analysis
Hole No. SP-3

Depth, Ft.	0 - 0.9	0.9-1.8	1.8-2.7
Laboratory No.	PC-2394	PC-2395	PC-2396
pH	7.4	7.2	6.8
Moisture, % of Dry Wt	45.8	62.3	80.8
Volitile Solids, % of Dry Wt	6.3	6.4	7.9
Conductivity, micromhos (a)	3720	2900	3220
Salinity, PPT of Dry Wt	40.0	28.5	45.1
Chemical Oxygen Demand, PPT of Dry Wt	31.8	43.2	45.8
Biological Oxygen Demand, PPM of Dry Wt	700	1006	1229
Total Kjeldahl Nitrogen (N), PPM of Dry Wt	1030	1380	1690
Phosphate (P), PPM of Dry Wt	0.2	0.5	0.7
Carbonate (CO_3), PPM of Dry Wt	30	33	52
Bicarbonate (HCO_3), PPM of Dry Wt	603	663	706
Sulfate (SO_4), PPM of Dry Wt	4140	3830	5470
Chloride (Cl), PPT of Dry Wt	19.0	11.0	21.3
Sulfide (S), PPM of Dry Wt	4-	77	47
Calcium (Ca), PPM of Dry Wt	438	266	419
Magnesium (Mg), PPM of Dry Wt	1030	524	997
Sodium-Potassium (Na), PPM of Dry Wt	1132	587	1321
Copper (Cu), PPM of Dry Wt	28	36	38
Cadmium (Cd), PPM of Dry Wt	0.1	0.1	0.1
Lead (Pb), PPM of Dry Wt	15	19	22
Iron (Fe), PPT of Dry Wt	40.8	40.6	47.0
Zinc (Zn), PPM of Dry Wt	76	92	88
Mercury (Hg), PPM of Dry Wt	0.4	0.5	0.5
Nickel (Ni), PPM of Dry Wt	82	94	96

(a) Conductivity of Suspension of 10g of sediment in 100g of water

TABLE 4
Alameda Creek
Sediment Analysis
Hole No. SP-4

Depth, Ft.	0 - 0.9	0.9-1.8	1.8-2.7
Laboratory No.	PC-2397	PC-2398	PC-2399
pH	7.2	7.3	7.0
Moisture, % of Dry Wt	48.7	68.6	73.0
Volitile Solids, % of Dry Wt	6.7	7.0	7.3
Conductivity, micromhos (a)	4160	2680	2720
Salinity, PPT of Dry Wt	47.5	26.6	33.1
Chemical Oxygen Demand, PPT of Dry Wt	39.6	49.9	49.1
Biological Oxygen Demand, PPM of Dry Wt	744	1855	1246
Total Kjeldahl Nitrogen (N), PPM of Dry Wt	505	1620	1870
Phosphate (P), PPM of Dry Wt	0.1	0.5	0.1
Carbonate (CO_3), PPM of Dry Wt	44	34	33
Bicarbonate (HCO_3), PPM of Dry Wt	549	951	906
Sulfate (SO_4), PPM of Dry Wt	4530	2790	3580
Chloride (Cl), PPT of Dry Wt	21.8	10.7	16.0
Sulfide (S), PPM of Dry Wt	128	387	168
Calcium (Ca), PPM of Dry Wt	450	149	239
Magnesium (Mg), PPM of Dry Wt	1090	408	623
Sodium-Potassium (Na), PPM of Dry Wt	1403	861	1034
Copper (Cu), PPM of Dry Wt	34	38	41
Cadmium (Cd), PPM of Dry Wt	0.1-	0.2	0.4
Lead (Pb), PPM of Dry Wt	16	22	22
Iron (Fe), PPT of Dry Wt	41.6	42.2	46.7
Zinc (Zn), PPM of Dry Wt	85	101	106
Mercury (Hg), PPM of Dry Wt	0.5	0.5	0.4
Nickel (Ni), PPM of Dry Wt	86	101	102

(a) Conductivity of Suspension of 10g of sediment in 100g of water

TABLE 5
Alameda Creek
Sediment Analysis
Hole No. SP-5

Depth, Ft.	0 - 0.9	0.9-1.8	1.8-2.7
Laboratory No.	PC-2400	PC-2401	PC-2402
pH	7.3	7.5	6.9
Moisture, % of Dry Wt	119.3	65.0	76.1
Volitile Solids, % of Dry Wt	7.0	6.9	8.0
Conductivity, micromhos (a)	3430	2370	3280
Salinity, PPT of Dry Wt	51.0	25.4	27.8
Chemical Oxygen Demand, PPT of Dry Wt	60.1	50.5	51.1
Biological Oxygen Demand, PPM of Dry Wt	1184	1320	740
Total Kjeldahl Nitrogen (N), PPM of Dry Wt	5610	840	1770
Phosphate (P), PPM of Dry Wt	0.5	0.3	1.0
Carbonate (CO_3), PPM of Dry Wt	53	34	41
Bicarbonate (HCO_3), PPM of Dry Wt	1064	1002	677
Sulfate (SO_4), PPM of Dry Wt	5240	3800	7130
Chloride (Cl), PPT of Dry Wt	48.0	21.0	22.9
Sulfide (S), PPM of Dry Wt	57	157	227
Calcium (Ca), PPM of Dry Wt	453	154	227
Magnesium (Mg), PPM of Dry Wt	908	526	357
Sodium-Potassium (Na), PPM of Dry Wt	1576	811	1247
Copper (Cu), PPM of Dry Wt	50	43	34
Cadmium (Cd), PPM of Dry Wt	0.2	0.4	0.2
Lead)Pb), PPM of Dry Wt	28	25	14
Iron (Fe), PPT of Dry Wt	59.2	44.6	44.0
Zinc (Zn), PPM of Dry Wt	130	116	89
Mercury (Hg), PPM of Dry Wt	0.6	0.4	0.4
Nickel (Ni), PPM of Dry Wt	134	111	90

(a) Conductivity of Suspension of 10g of sediment in 100g of water

TABLE 6
Alameda Creek
Sediment Analysis
Hole No. SP-6

Depth, Ft.	0 - 0.8	0.8-1.7	1.7-2.5
Laboratory No.	PC-2403	PC-2404	PC-2405
pH	7.1	7.2	7.4
Moisture, % of Dry Wt	43.6	48.7	41.2
Volitile Solids, % of Dry Wt	6.0	5.3	6.7
Conductivity, micromhos (a)	3700	2310	2700
Salinity, PPT of Dry Wt	34.9	19.3	23.3
Chemical Oxygen Demand, PPT of Dry Wt	34.5	33.7	43.3
Biological Oxygen Demand, PPM of Dry Wt	486	387	988
Total Kjeldahl Nitrogen (N), PPM of Dry Wt	1080	1110	1280
Phosphate (P), PPM of Dry Wt	0.1	0.7	0.5
Carbonate (CO_3), PPM of Dry Wt	29	34	28
Bicarbonate (HCO_3), PPM of Dry Wt	587	659	601
Sulfate (SO_4), PPM of Dry Wt	3870	3220	2280
Chloride (Cl), PPT of Dry Wt	14.0	12.6	19.8
Sulfide (S), PPM of Dry Wt	31	120	542
Calcium (Ca), PPM of Dry Wt	342	162	113
Magnesium (Mg), PPM of Dry Wt	720	270	327
Sodium-Potassium (Na), PPM of Dry Wt	1045	574	753
Copper (Cu), PPM of Dry Wt	29	28	30
Cadmium (Cd), PPM of Dry Wt	0.1	0.2	0.2
Lead (Pb), PPM of Dry Wt	17	16	16
Iron (Fe), PPT of dry Wt	38.8	37.2	36.7
Zinc (Zn), PPM of Dry Wt	78	78	78
Mercury (Hg), PPM of Dry Wt	0.4	0.4	0.4
Nickel (Ni), PPM of Dry Wt	80	80	81

(a) Conductivity of Suspension of 10g of sediment in 100g of water

TABLE 7
Alameda Creek
Sediment Analysis
Hole No. SP-7

Depth, Ft	0 - 0.9	0.9-1.9	1.9-2.8
Laboratory No.	PC-2406	PC-2407	PC-2408
pH	6.9	7.2	7.4
Moisture, % of Dry Wt	31.2	46.9	54.9
Volitile Solids, % of Dry Wt	6.7	5.7	5.8
Conductivity, micromhos (a)	4370	1930	1950
Salinity, PPT of Dry Wt	42.1	18.5	19.4
Chemical Oxygen Demand, PPT of Dry Wt	35.2	34.8	42.8
Biological Oxygen Demand, PPM of Dry Wt	577	705	867
Total Kjeldahl Nitrogen (N), PPM of Dry Wt	1080	1080	1200
Phosphate (P), PPM of Dry Wt	0.4	0.4	1.3
Carbonate (CO_3), PPM of Dry Wt	34	32	44
Bicarbonate (HCO_3), PPM of Dry Wt	552	659	742
Sulfate (SO_4), PPM of Dry Wt	3410	3860	3110
Chloride (Cl), PPT of Dry Wt	20.2	6.9	8.3
Sulfide (S), PPM of Dry Wt	11	134	178
Calcium (Ca), PPM of Dry Wt	356	217	133
Magnesium (Mg), PPM of Dry Wt	742	263	237
Sodium-Potassium (Na), PPM of Dry Wt	1274	500	584
Copper (Cu), PPM of Dry Wt	31	28	32
Cadmium (Cd), PPM of Dry Wt	0.2	0.2	0.2
Lead (Pb), PPM of Dry Wt	14	15	17
Iron (Fe), PPT of Dry Wt	38.0	38.2	37.2
Zinc (Zn), PPM of Dry Wt	77	76	85
Mercury (Hg), PPM of Dry Wt	0.4	0.4	0.2
Nickel (Ni), PPM of Dry Wt	83	82	91

(a) Conductivity of Suspension of 10g of sediment in 100g of water

TABLE 8
Alameda Creek
Sediment Analysis
Hole No. SP-8

Depth, Ft	0 - 0.9	0.9-1.8	1.8-2.7
Laboratory No.	PC-2409	PC-2410	PC-2411
pH	7.2	7.4	7.4
Moisture, % of Dry Wt	54.5	72.9	80.4
Volitile Solids, % of Dry Wt	7.4	7.7	7.1
Conductivity, micromhos (a)	3960	1970	2260
Salinity, PPT of Dry Wt	41.7	22.5	24.9
Chemical Oxygen Demand, PPT of Dry Wt	42.9	68.4	57.8
Biological Oxygen Demand, PPM of Dry Wt	711	1383	974
Total Kjeldahl Nitrogen (N), PPM of Dry Wt	1400	2000	1840
Phosphate (P), PPM of Dry Wt	0.1-	0.4	2.6
Carbonate (CO_3), PPM of Dry Wt	39	42	49
Bicarbonate (HCO_3), PPM of Dry Wt	827	895	1338
Sulfate (SO_4), PPM of Dry Wt	3640	2530	2510
Chloride (Cl), PPT of Dry Wt	20.0	9.8	11.2
Sulfide (S), PPM of Dry Wt	11	193	83
Calcium (Ca), PPM of Dry Wt	349	121	141
Magnesium (Mg), PPM of Dry Wt	694	112	306
Sodium-Potassium (Na), PPM of Dry Wt	1258	724	787
Copper (Cu), PPM of Dry Wt	39	36	38
Cadmium (Cd), PPM of Dry Wt	0.2	0.3	0.2
Lead (Pb), PPM of Dry Wt	19	17	25
Iron (Fe), PPT of Dry Wt	40.2	43.2	43.3
Zinc (Zn), PPM of Dry Wt	100	100	99
Mercury (Hg), PPM of Dry Wt	0.4	0.3	0.4
Nickel (Ni), PPM of Dry Wt	97	104	101

(a) Conductivity of Suspension of 10g of sediment in 100g of water

TABLE 9
Alameda Creek
Sediment Analysis
Hole No. SP-9

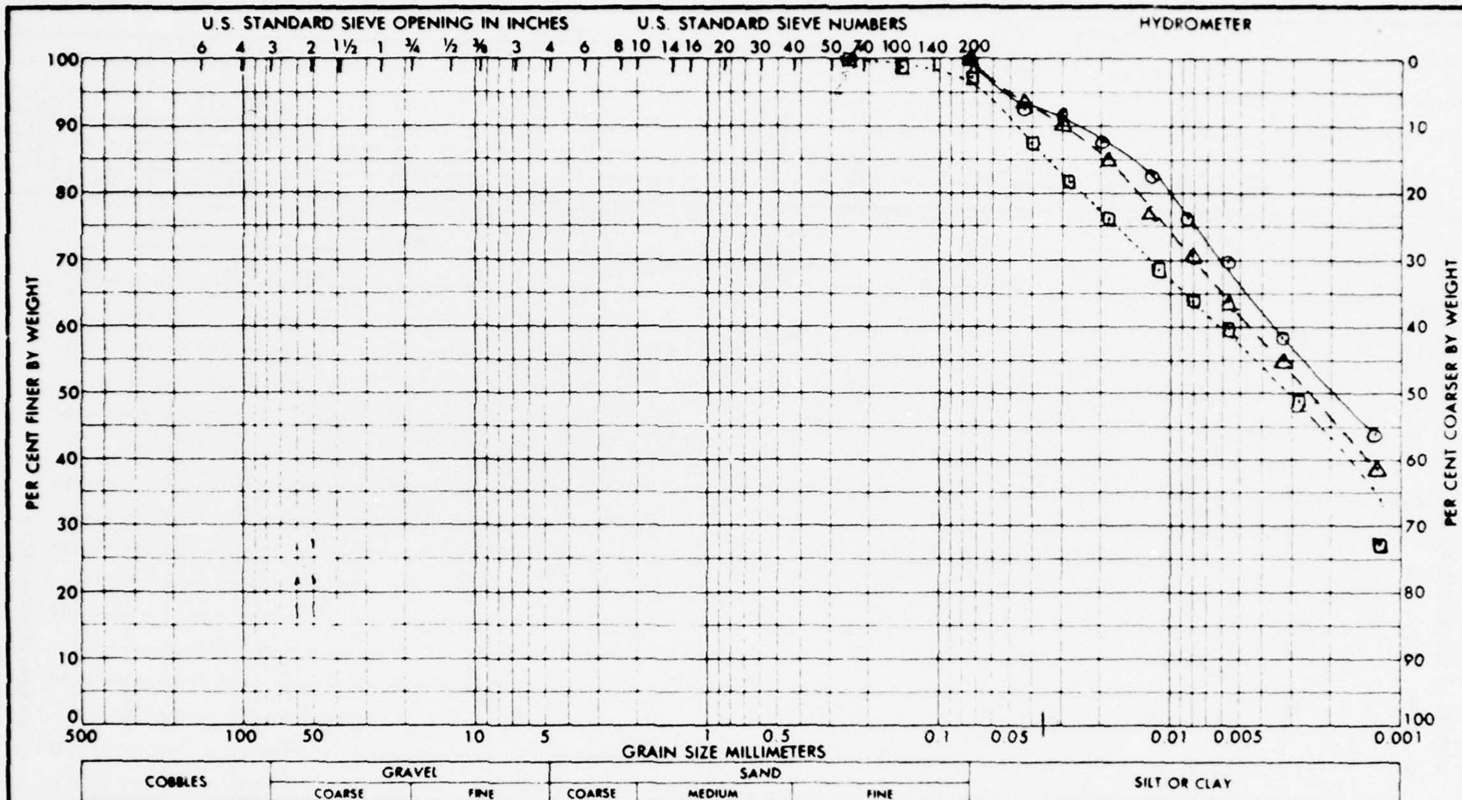
Depth, Ft	0 - 0.8	0.8-1.7	1.7-2.5
Laboratory No.	PC-2412	PC-2413	PC-2414
pH	7.2	7.4	7.4
Moisture, % of Dry Wt	42.1	65.4	75.6
Volitile Solids, % of Dry Wt	6.7	7.0	7.3
Conductivity, micromhos (a)	3880	2310	2350
Salinity, PPT of Dry Wt	44.9	23.8	25.2
Chemical Oxygen Demand, PPT of Dry Wt	33.3	57.4	54.5
Biological Oxygen Demand, PPM of Dry Wt	426	794	1018
Total Kjeldahl Nitrogen (N), PPM of Dry Wt	1110	1640	1640
Phosphate (P), PPM of Dry Wt	0.2	0.3	2.8
Carbonate (CO_3), PPM of Dry Wt	42	51	57
Bicarbonate (HCO_3), PPM of Dry Wt	666	1145	1298
Sulfate (SO_4), PPM of Dry Wt	3730	3470	2510
Chloride (Cl), PPT of Dry Wt	21.0	9.7	12.0
Sulfide (S), PPM of Dry Wt	3-	9	314
Calcium (Ca), PPM of Dry Wt	432	168	153
Magnesium (Mg), PPM of Dry Wt	1020	317	226
Sodium-Potassium (Na), PPM of Dry Wt	1313	742	811
Copper (Cu), PPM of Dry Wt	30	39	42
Cadmium (Cd), PPM of Dry Wt	0.2	0.1-	0.4
Lead (Pb), PPM of Dry Wt	17	19	25
Iron (Fe), PPT of Dry Wt	38.4	43.0	45.6
Zinc (Zn), PPM of Dry Wt	78	100	107
Mercury (Hg), PPM of Dry Wt	0.3	0.3	0.4
Nickel (Ni), PPM of Dry Wt	87	108	105

(a) Conductivity of Suspension of 10g of sediment in 100g of water

TABLE 10
Alameda Creek
Sediment Analysis
Hole No. SP-10

Depth, Ft.	0 - 0.8	0.8-1.7	1.7-2.5
Laboratory No.	PC-2415	PC-2416	PC-2417
pH	6.9	7.6	7.1
Moisture, % of Dry Wt	50.9	56.3	78.3
Volitile Solids, % of Dry Wt	8.5	6.4	8.8
Conductivity, micromhos (a)	5310	2470	3520
Salinity, PPT of Dry Wt	58.5	25.0	44.6
Chemical Oxygen Demand, PPT of Dry Wt	59.3	44.3	69.9
Biological Oxygen Demand, PPM of Dry Wt	694	469	856
Total Kjeldahl Nitrogen (N), PPM of Dry Wt	1730	1390	2240
Phosphate (P), PPM of Dry Wt	0.1-	0.5	0.1-
Carbonate (CO_3), PPM of Dry Wt	72	45	61
Bicarbonate (HCO_3), PPM of Dry Wt	859	1189	1338
Sulfate (SO_4), PPM of Dry Wt	5200	3580	4160
Chloride (Cl), PPT of Dry Wt	27.0	11.0	21.2
Sulfide (S), PPM of Dry Wt	5	125	86
Calcium (Ca), PPM of Dry Wt	563	329	376
Magnesium (Mg) PPM of Dry Wt	1350	448	924
Sodium-Potassium (Na), PPM of Dry Wt	1618	761	1297
Copper (Cu), PPM of Dry Wt	38	38	38
Cadmium (Cd), PPM of Dry Wt	0.3	0.5	0.5
Lead (Pb), PPM of Dry Wt	17	19	18
Iron (Fe), PPT of Dry Wt	39.2	40.6	41.0
Zinc (Zn), PPM of Dry Wt	100	108	103
Mercury (Hg), PPM of Dry Wt	0.2	0.4	0.3
Nickel (Ni), PPM of Dry Wt	98	102	109

(a) Conductivity of Suspension of 10g of sediment in 100g of water



SAMPLE NO	ELEV OR DEPTH	CLASSIFICATION	NAT W%	LL	PL	PI
2388	0.0 - 0.9	——⊙—— Clay (CH)		99	36	63
2389	0.9 - 1.9	- - -△- - - Clay (CH)		97	33	64
2390	1.9 - 2.8	······□······ Clay (CH)		87	33	54

PROJECT ALAMEDA CREEK

AREA

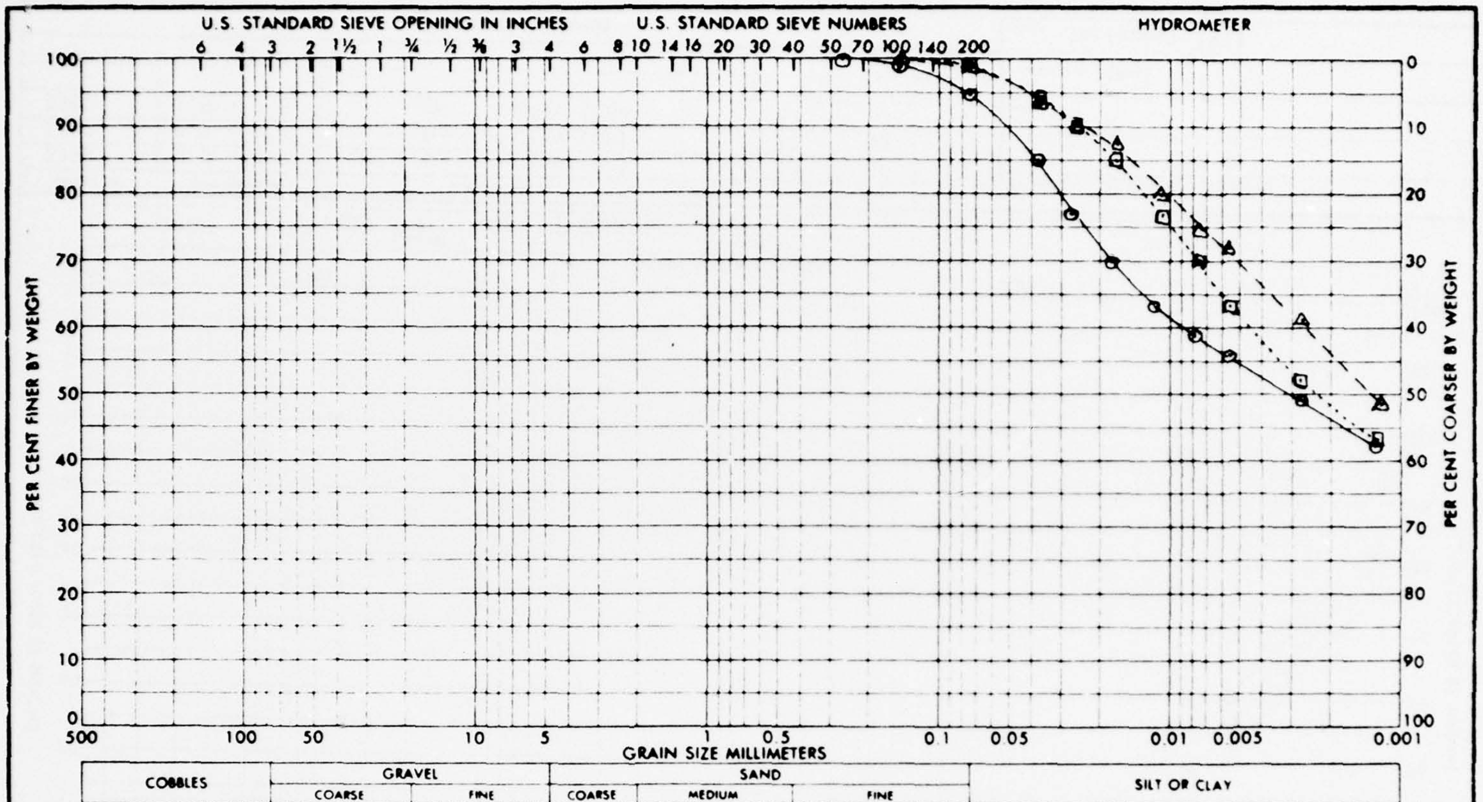
BORING NO SP-1

DATE September 1975

GRADATION CURVES

ENG FORM 1 MAY 63 **2087** REPLACES WES FORM NO 1241, SEP 1962, WHICH IS OBSOLETE

Plate 1



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2391	0 - 0.9	—○— Clay (CH)		76	30	46
2392	0.9 - 1.9	- -△- - Clay (CH)		100	34	66
2393	1.9 - 2.8	·····□····· Clay (CH)		109	34	75

GRADATION CURVES

PROJECT ALAMEDA CREEK

AREA

BORING NO SP-2

DATE September 1975

ENG FORM 2087
1 MAY 63

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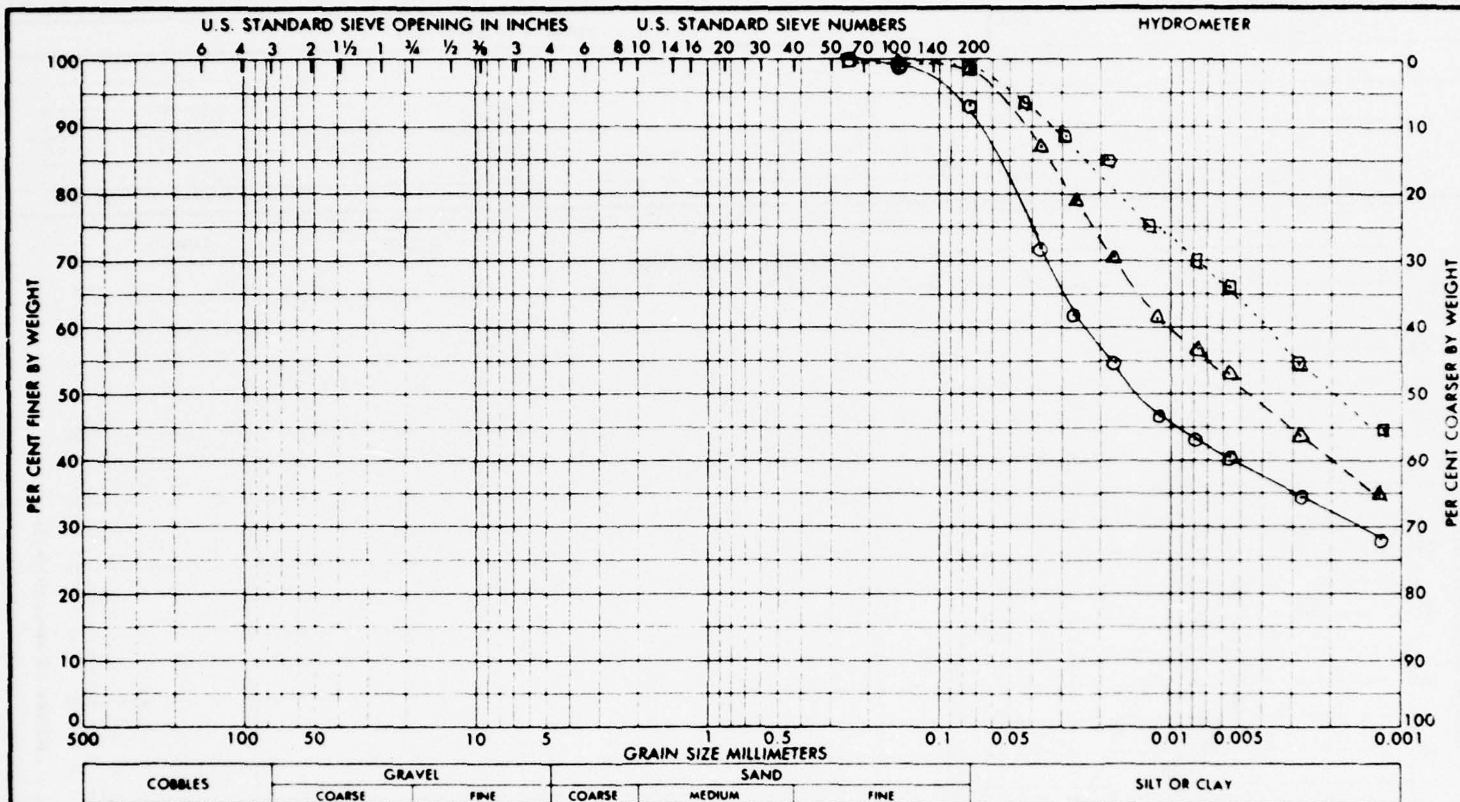
Plate 2



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2394	0 - 0.9	—○—	Clay (CH)		60	26	34
2395	0.9 - 1.8	--△--	Clay (CH)		78	29	49
2396	1.8 - 2.7	··□···	Clay (CH)		96	33	63

PROJECT ALAMEDA CREEK

AREA

BORING NO SP-3

DATE September 1975

GRADATION CURVES

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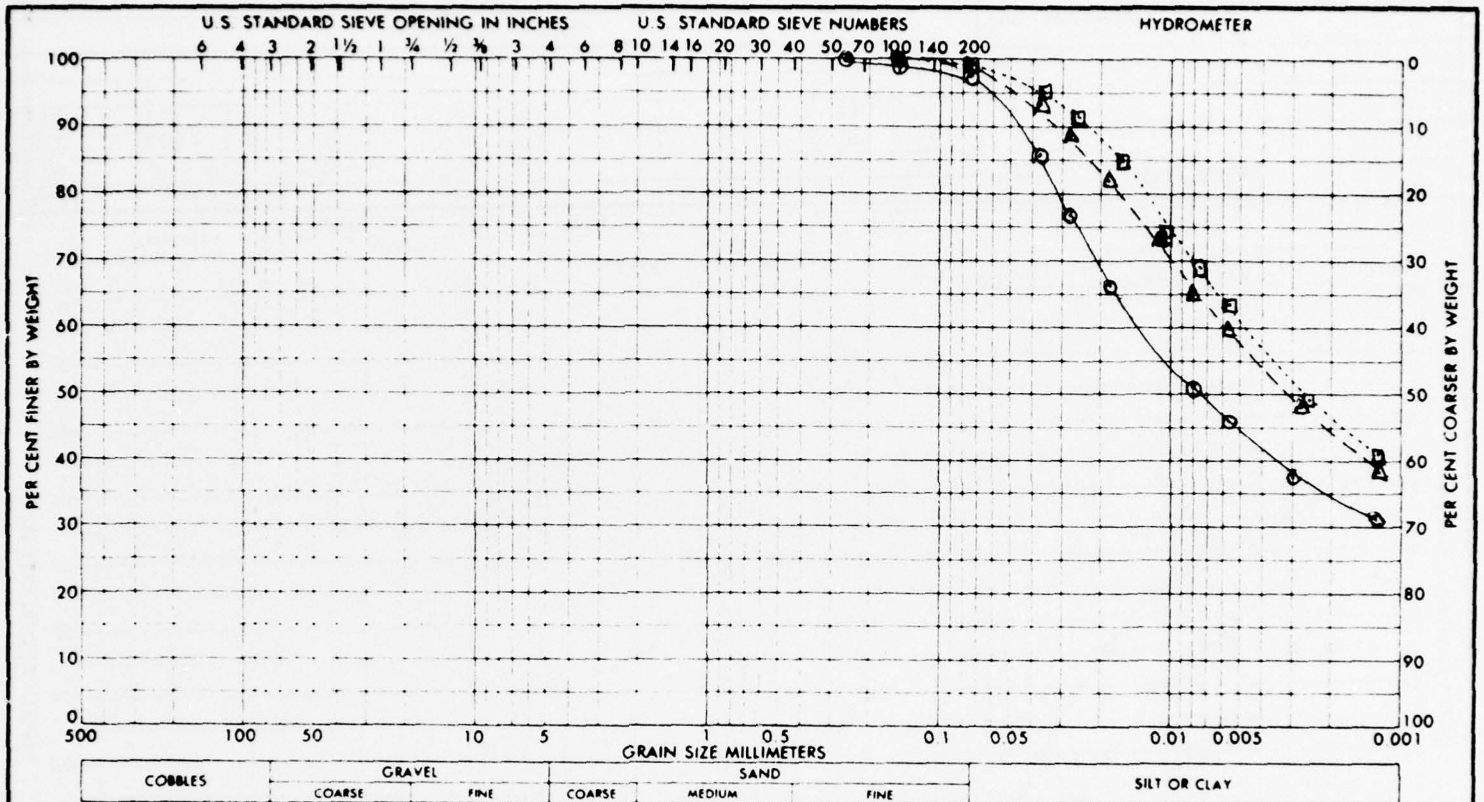
Plate 3



SAMPLE NO	ELEV OR DEPTH	CLASSIFICATION	NAT W%	LL	PL	PI
2327	0-0.9	—○— Clay(CH)		73	29	44
2328	0.9-1.8	--△-- Clay(CH)		91	32	59
2329	1.8-2.7	····□···· Clay(CH)		95	32	63

GRADATION CURVES

PROJECT: ALAMEDA CREEK

AREA:

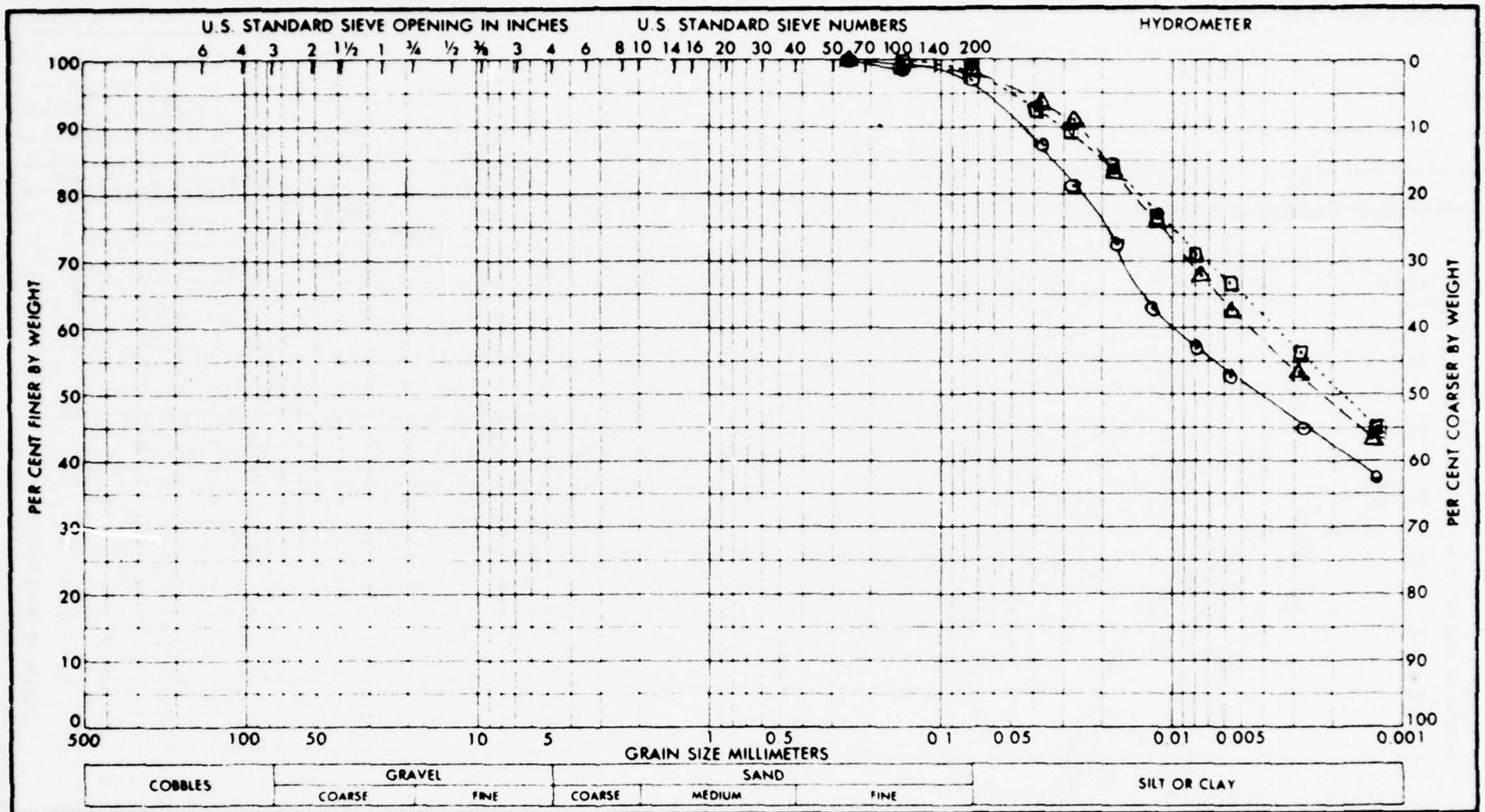
BORING NO: SP-4

DATE: September 1975

ENG FORM 2087
1 MAY 63

REPLACES WES FORM NO 1241, SEP 1962, WHICH IS OBSOLETE

Plate 4



SAMPLE NO	ELEV OR DEPTH	CLASSIFICATION	NAT W%	LL	PL	PI
2400	0-0.9	—⊖— Clay(CH)		76	30	46
2401	0.9-1.8	- -△- - Clay(CH)		90	32	58
2402	1.8-2.7	····⊡···· Clay(CH)		97	33	64

PROJECT ALAMEDA CREEK

AREA

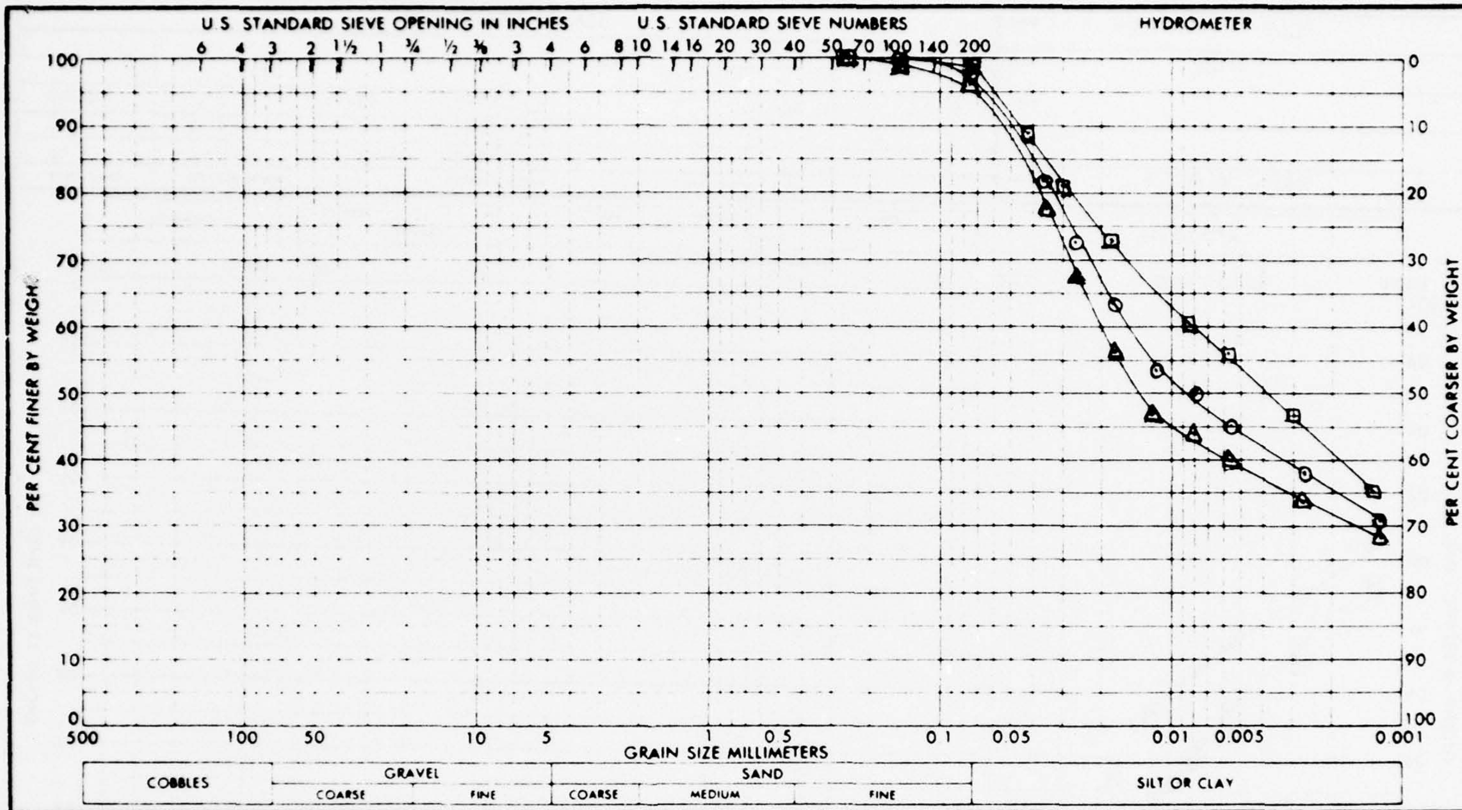
BORING NO SP-5

DATE September 1975

GRADATION CURVES

ENG FORM 2087
1 MAY 63

REPLACES WES FORM NO 1241, SEP 1962, WHICH IS OBSOLETE



SAMPLE NO	ELEV OR DEPTH	CLASSIFICATION	NAT W%	LL	PL	PI
2403	0-0.8	Clay (CH)		63	26	37
2404	0.8-1.7	Clay (CH)		63	24	39
2405	1.7-2.5	Clay (CH)		87	31	56

PROJECT ALAMEDA CREEK

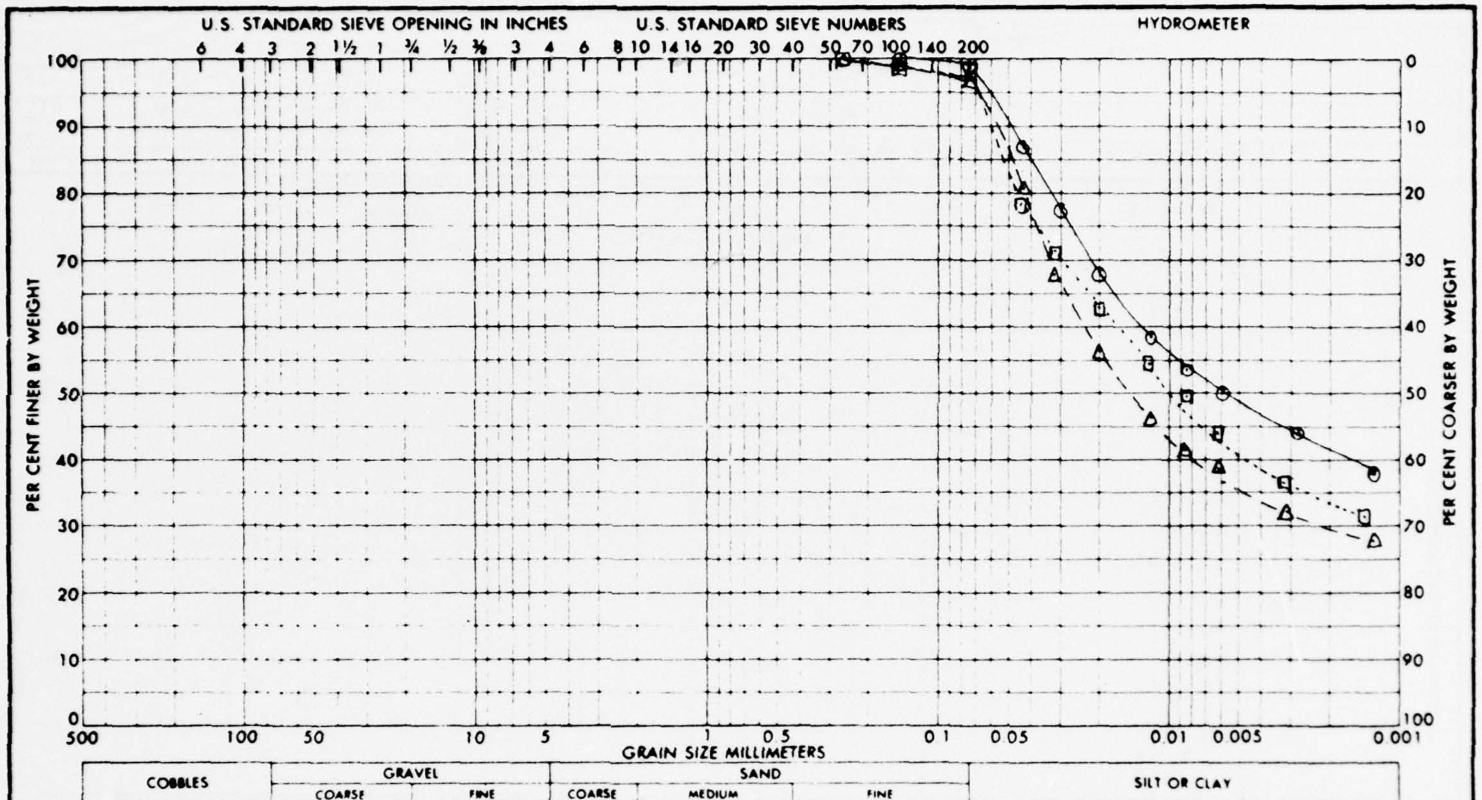
AREA

BORING NO SP-6

DATE September 1975

GRADATION CURVES

ENG FORM 2087 1 MAY 63 REPLACES WES FORM NO 1241 SEP 1962, WHICH IS OBSOLETE



SAMPLE NO	ELEV OR DEPTH		CLASSIFICATION	NAT W%	LL	PL	PI
2406	0 - 0.9	—○—	Clay (CH)		65	28	37
2407	0.9 - 1.9	- -△- -	Clay (CH)		65	26	39
2408	1.9 - ·.8	····□····	Clay (CH)		74	27	47

PROJECT ALAMEDA CREEK

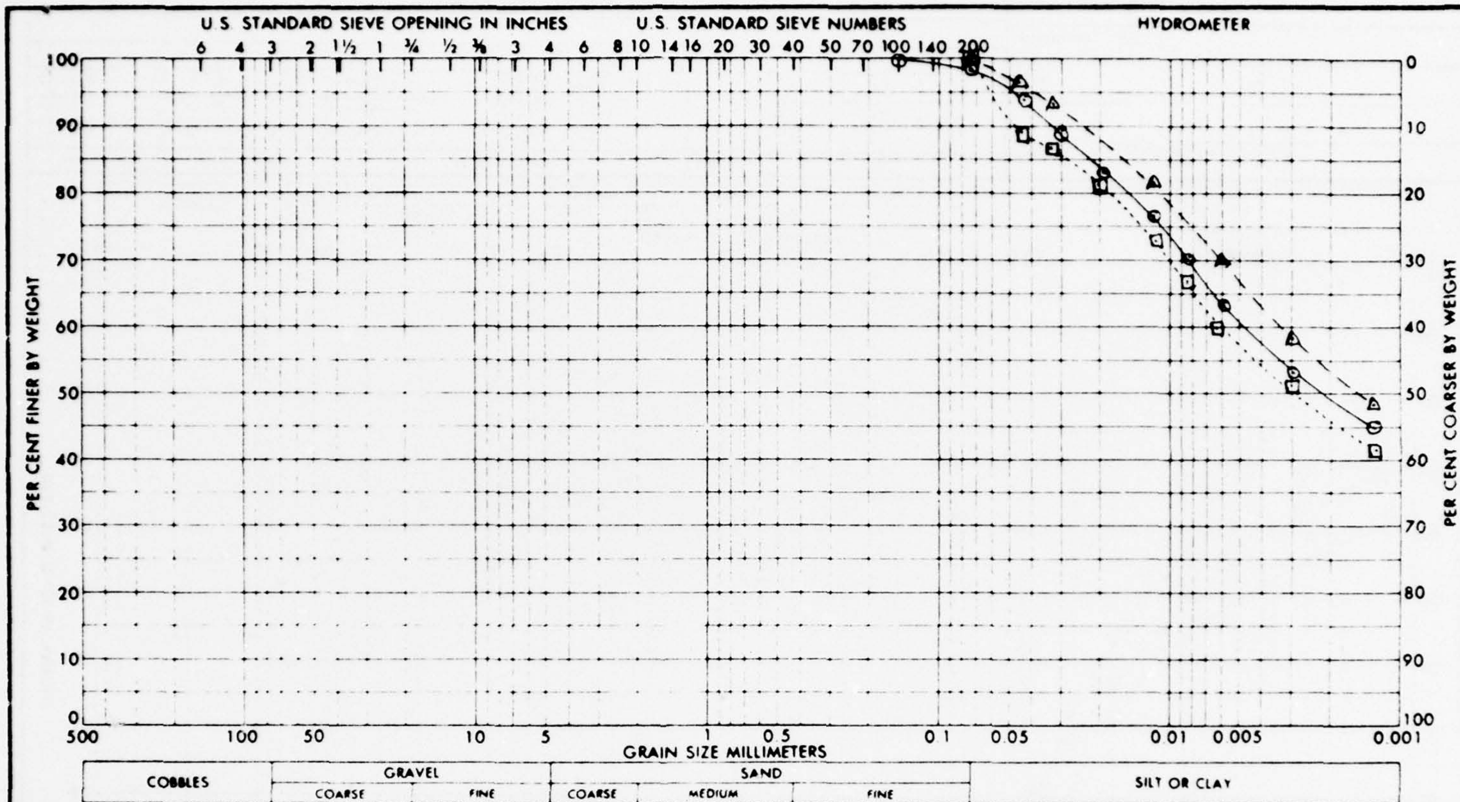
AREA

BORING NO SP-7

DATE September 1975

GRADATION CURVES

ENG FORM 2087
1 MAY 63
REPLACES WES FORM NO 1241, SEP 1962, WHICH IS OBSOLETE



SAMPLE NO	ELEV OR DEPTH		CLASSIFICATION	NAT W%	LL	PL	PI
2409	0 - 0.9	—○—	Clay (CH)		87	32	55
2410	0.9 - 1.8	--△--	Clay (CH)		112	36	76
2411	1.8 - 2.7	···□···	Clay (CH)		98	33	65

PROJECT ALAMEDA CREEK

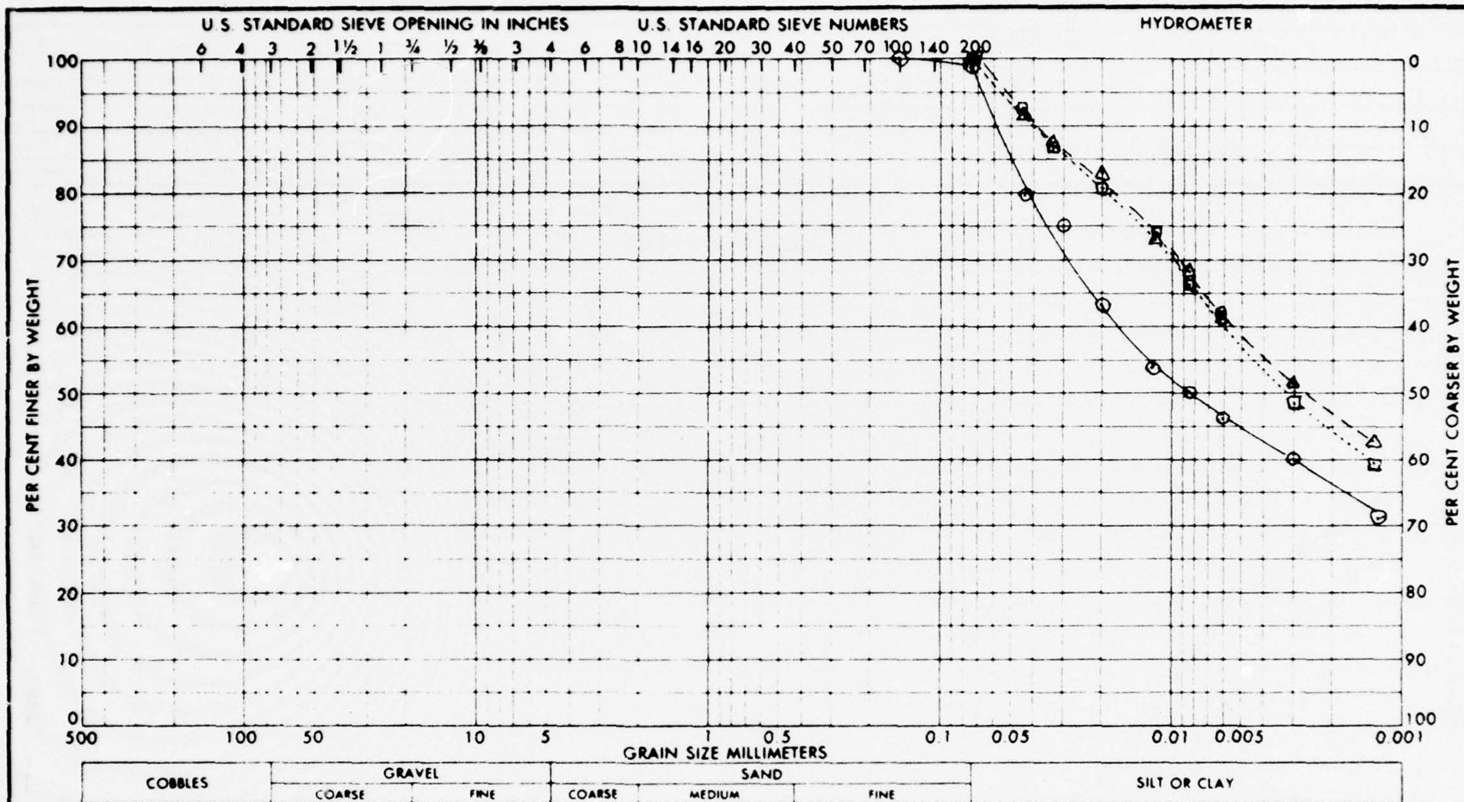
AREA

BORING NO SP-8

DATE September 1975

GRADATION CURVES

ENG FORM 2087
1 MAY 63
REPLACES WES FORM NO 1241, SEP 1962, WHICH IS OBSOLETE



SAMPLE NO	ELEV OR DEPTH	CLASSIFICATION		NAT W%	LL	PL	PI
2412	0 - 0.8	—⊙—	Clay (CH)		65	28	37
2413	0.8 - 1.7	- - △ - -	Clay (CH)		101	36	65
2414	1.7 - 2.5	····□····	Clay (CH)		99	34	65

PROJECT ALAMEDA CREEK

AREA

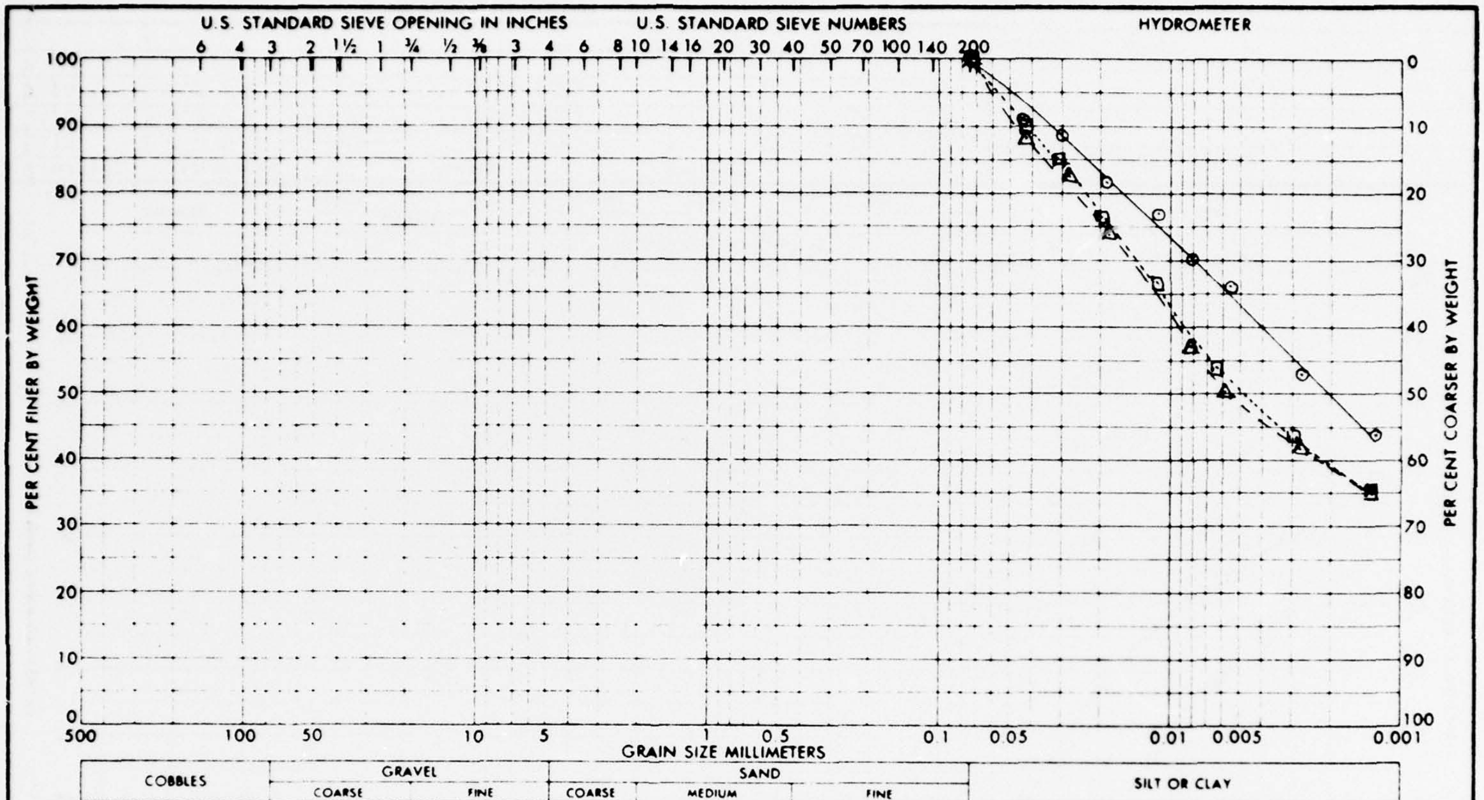
BORING NO SP-9

DATE September 1975

GRADATION CURVES

ENG FORM 2087 1 MAY 63 REPLACES WES FORM NO 1241, SEP 1962, WHICH IS OBSOLETE

Plate 9



SAMPLE NO	ELEV OR DEPTH	CLASSIFICATION		NAT W%	LL	PL	PI
2415	0 - 0.8	—○—	Clay (CH)		95	36	59
2416	0.8 - 1.7	--△--	Clay (CH)		78	28	50
2417	1.7 - 2.5	---□---	Clay (CH)		94	33	61

PROJECT ALAMEDA CREEK

AREA

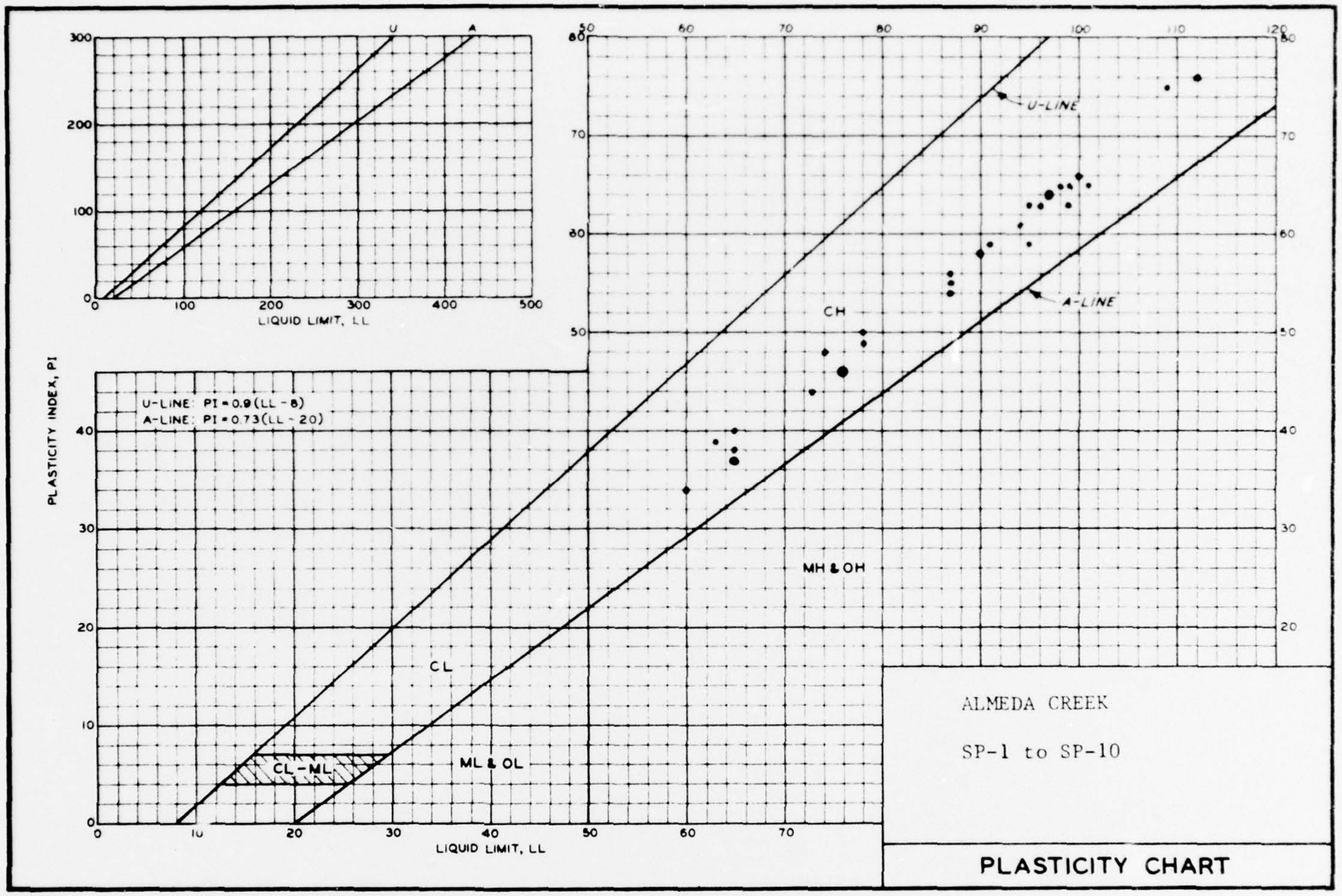
BORING NO SP-10

DATE September 1975

GRADATION CURVES

ENG FORM 2087
1 MAY 63

REPLACES WES FORM NO 1241, SEP 1962, WHICH IS OBSOLETE



ENG FORM 4334
JUNE 1970

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